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# ELEMENTS OF PHYSICS.

VOL. II.

LONDON:
Printed by A. SPOTTISWOODE,
New-Street-Square.

# ELEMENTS

OF

# PHYSICS.

BY

## C. F. PESCHEL,

PRINCIPAL OF THE ROYAL MILITARY COLLEGE AT DRESDEN,
ETC.

TRANSLATED FROM THE GERMAN,

WITH NOTES,

## BY E. WEST.

Illustrated with Diagrams and Woodcuts.

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## PART II.

## IMPONDERABLE BODIES.

### I. — LIGHT, HEAT, AND MAGNETISM.

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1846.

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# TRANSLATOR'S PREFACE.

N presenting to the English reader the Second Part of ‘Peschel's Elements of Physics," I may observe that it vas with feelings of considerable satisfaction I received an ntimation from my publishers that the sale of Part I. was o encouraging as to render it desirable that the work hould be completed with as little delay as possible. It vas gratifying to find that the estimate I had formed of he merits of my author was thus confirmed by the verdict f public opinion. The brief intervals of leisure which rofessional engagements have allowed me have been faithully devoted to the preparation of these volumes.

I am bound to acknowledge the handsome treatment of he First Volume by the reviewers in general; and to the ditors of the *Eclectic Review* and the *Civil Engineer and lrchitect's Journal* my thanks are especially due for their engthened notices of it. The suggestion offered as to the eduction of ALL the measures to English standards has een attended to in the present Volumes. The different ormulæ which occur in the Chapter on Heat have been dapted to Fahrenheit's scale; those calculated for the entigrade division are likewise retained for the convenience f any students who may have occasion to refer to foreign cientific works. Instead of a table of the tension of team from 32° to 212°, calculated from Arzberger's ormula, I have substituted one at page 223., Vol. II., resenting at a single view the results of Watt's, Dalton's, Jre's, and Southern's observations, together with the force according to a formula of Tredgold's; the tables which I have thus brought together are borrowed from that gentleman's work on the steam-engine.

Instead of detaining the reader with any remarks of my own as to the general plan of the work, I would call his attention to the extract given on the next page from M. Peschel's Preface.

I have added corrections of such errors in the first Volume as had escaped my notice at the time of its passing through the press; I have endeavoured to render the present Volumes as accurate as possible; how far I have been successful, it remains for the public to decide. Any suggestions that may be offered for the improvement of a second edition will be thankfully received.

AMERSHAM,
*July* 14. 1846.

# EXTRACT

FROM

# THE AUTHOR'S PREFACE.

"A MATTER of considerable difficulty in the preparation of a manual like the present is to determine the just proportions of the respective sections, chapters, and paragraphs, so that the subject shall be treated of in a manner neither too brief nor too diffuse. The purpose for which the treatise is intended will chiefly guide the author, who may yet, after all, be biassed to some extent by his individual views; for this reason a few remarks are added, explanatory of the course pursued.

"Among the Chapters that treat of the physical forces in general is one in which the leading phenomena of chemical attraction are explained. The varied relations in which Chemistry now stands to Natural Philosophy renders some acquaintance with its leading principles indispensable, or else many points in natural science, and especially what refers to Electricity, will be unintelligible. The chapter allotted to this subject is restricted to an explanation of the laws of affinity, the chemical division of substances into simple and compound, and chemical nomenclature and symbols; details as to the properties of particular substances are omitted, as belonging rather to a treatise on chemistry. The dynamics and statics of solid, liquid, and aëriform bodies are treated of in such a manner that a

student may gain a theoretical knowledge of them
the aid of the higher mathematics. Crystall
occupies only a few pages, but the strength of m
and the application of a solid's elasticity to measur
are discussed at length. As the undulatory theory
stantly extending its domains in the physics of imp
able bodies, and is daily gaining new adherents, it is
sary to keep it in view in compiling a work on the r
sciences. The basis of this important theory is th
trine of undulations, for the scientific developme
which we are indebted to the MM. Weber. Pro
Eisenlohr's services in this department are so great,
his views so comprehensive, that the chapter on this su
in his excellent "Lehrbuch der Physik," appeared to
author an unexceptionable model, and he has accordi
adopted the same systematic arrangement. In the sec
on acoustics, but a cursory notice has been taken of
theory of music, as being most in accordance with
character of this work.

"In the Second Volume the phenomena of the imp
derable substances are explained, both according to
undulatory and corpuscular theories; in this portion of
treatise the phenomena attending the interference, the
fraction, and polarisation of light, those of radiant h
&c. &c., will be found to be handled at such length as
limits of the work allowed. The greatest difficulty
how to treat of Electricity, especially with reference to
theory of voltaic electricity, the range of electrical scie
having become so extended, and the decision of
scientific world being still suspended with regard to
different theoretical views which are held as the origin
voltaic electricity. The author felt that he must ad
one view or the other; and though he has decided
favour of the theory of contact, he has not omitted
adduce the strongest arguments by which the chem
theory is supported; and, in conclusion, he has presen
the reader with the sketch of an intermediate theory.
last section treats of Electro-dynamics, the phenomen

Electro-magnetism being first brought under review, and afterwards those of Magneto-electricity.

"A different arrangement of the type" [which has been adopted also in the translation] "distinguishes the paragraphs that contain the outline and general principles of the sciences from the supplementary matter, which enters more into detail; it is thought that this plan will be found convenient both for teaching and for self-instruction, as affording an opportunity of going more or less thoroughly into the subject, as may appear desirable.

"These supplementary observations contain also the mathematical demonstrations of the different doctrines, so far at least as they can be supplied by means of the elementary mathematics; experiments which may give the impress of truth to the theoretical paragraphs; brief notices of matters universally known or of minor importance; and fuller details of subjects less generally known, or with which it is desirable that the student should be well acquainted."

# CORRIGENDA.

| | | | | | |
|---|---|---|---|---|---|
| Vol. I. p. 19. | line 14 from top, | for | $-ab \cdot ac \cdot \cos.$ | read | $-2ab \cdot ac \cdot \cos.$ |
| 44. | 17 | - | *co. vers. sin.* | - | *vers. sin.* |
| — | 22 | - | co. vers. sin. | - | vers. sin. |
| 54. | 6 from bottom | | $h : H$ | - | $H : h.$ |
| 111. | 7 from top | | $\frac{(mMV+mv)}{M+m}$ | - | $\frac{m(MV-mv)}{M+m}.$ |
| 112. | 3 from bottom; | | ninth | - | seventh. |
| 155. | 7 from top | | *the vessel* | - | *a cylindric or pris-<br>matic vesse* |
| 162. | 19 | - | $\left(\frac{f^2}{J^2} C - J\right)$ | - | $\frac{f^2}{J^2}(C-J).$ |
| — | 21 | - | Do. | - | Do. |
| 165. | 3 from bottom | | 2 | - | $\frac{1}{2}.$ |
| — | 2 | - | 50·70=3500 | - | 50·72=3600. |
| 229. | 8 | - | hydrogen | - | aqueous vapour. |
| 230. | 8 from top | | Do. | - | Do. |
| 235. | 5 | - | B—(log. $\beta'$, &c. | - | $\beta$—(log. $\beta'$, &c. |
| 240. | 14 from bottom | | $l=-12{\cdot}3$ | - | $t=-12{\cdot}3.$ |
| Vol. III. p. 12. | 17 from top | | ἰλεκτρον | - | ἤλεκτρον. |
| 78. | 4 from bottom | | electrometers | - | electromotors. |

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OF

# THE SECOND VOLUME.

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# ELEMENTS

## OF THE

# PHYSICS OF IMPONDERABLE BODIES.

---

## IMPONDERABLE SUBSTANCES, OR ETHEREAL POWERS IN GENERAL.

### § 270.

THE phenomena of *Light, Heat, Electricity*, and *Magnetism* are so peculiar in their nature that we cannot assume that they result from those general and fundamental properties of matter which have been treated of in the former volume of this work.

The distinguishing characteristic of these substances (if such they be) is, that they are not permanently resident in those bodies in which their presence is observed: they also affect our senses peculiarly; thus, light excites no organs but those of vision, heat acts only on our feeling; electricity, on the contrary, influences all our senses, whilst magnetism exerts upon our frames no perceptible influence whatever. Light appears to be diffused throughout the universe, but heat, electricity and magnetism, have not as yet been proved to exist beyond the limits of our globe; it is, however, highly probable that their range is as wide as that of light.

### § 271.

The generally prevailing theories by which it is proposed to explain the various phenomena of the imponderable substances are two.

Some philosophers assume for this purpose the existence of a peculiar *class of substances* differing from all the other forms of matter in this, that they are not subject to the laws of gravity, and that they are consequently destitute of weight, whence the term *Imponderable Substances*: they further suppose them to be of so subtile a nature as to pass through all other material bodies, by which, therefore, they cannot be either inclosed or divided.

According to the other hypothesis, a certain imponderable, highly elastic fluid, styled the *ether*, is supposed to fill all space throughout the universe, and to occupy the vacancies between the atoms of bodies: on this fluid different forces are conceived to act, so as to produce the effects known to us as light, heat, *etc.*

## § 272.

These ethereal forces, whose nature is involved in great obscurity, possess one remarkable property, called *Polarity*, which is most perfectly developed in electricity and magnetism. Polarity consists in the tendency shown by two contrary *polar forces* to become united, and in the efforts of each polar force to excite its opposite in other bodies, whence similar polar forces invariably repel each other. When these opposite forces effect such a union as mutually to destroy each other's energies, all their external operations cease, and the forces are said to be *neutralised* and the condition thus obtained is one of equilibrium or rest. Polar energy displays itself in a disturbance of the polar forces by external causes, and this disturbance continues until a perfect neutralisation is re-established. When the forces are in this state of activity a body is said to be *polarised*, and the points at which their energy is most strongly marked are denominated *poles*. The signs + and −, which represent opposite values in mathematics, have been adopted as the symbols of these forces; whence the law of polarity may be thus expressed; + and − polarity represent attraction, + and + or − and − repulsion, and equal + and − give 0, *i.e.* neutralisation, equilibrium, or rest.

From the rapid advances recently made in this department of natural science, and from the analogies which present themselves between light and heat, electricity and magnetism, we are led to the conclusion that, probably, the phenomena of these four ethereal forces are, after all, but modifications of a higher principle with which we are not yet acquainted; a principle that, perhaps, plays an important part in the obscure operations of that vitality which animates all organised beings.

# PART I.

## LIGHT, HEAT, MAGNETISM.

## SECTION I.

## LIGHT.

### I. OF LIGHT IN GENERAL.

§ 273.

*Light* renders all external objects visible; the organ through e medium of which we become acquainted with the universe round us is the eye, as the action of light upon it immediately ffects the optic nerve. Light has also the property of *comunicating heat* and producing certain *chemical*, *electrical*, and *agnetic* (?) *effects*, so that it exercises an important influence on ll organised bodies.

In the following chapters those phenomena which are caused by the first-named property of light will be described and explained, and such as result from the other properties we have mentioned will be noticed at the close of this section, and in the sections on Heat, Electricity, and Magnetism.

§ 274.

To give a complete explanation of the various phenomena of ght, it would be requisite for us to have an accurate knowledge f its nature: since we do not possess this, recourse has been had o theories, two of which are the most generally received, viz., he *Emanation* or *Corpuscular Theory*, and the *Undulatory Theory*.

According to the former of these hypotheses, light is an imonderable substance, whose inconceivably minute particles roduce the sensation of sight by their action on the eye, in a anner analogous to that in which the fine particles of any dorous substance excite the sense of smell. The atoms of ght are further supposed to be subject to the attractive and epulsive forces of the bodies on whose surfaces they fall, and ith regard to these forces to display different degrees of inertia.

*Newton* originally constructed this hypothesis, which has been still further developed by *Biot* and *Laplace*.

According to the *Undulatory Theory*, light is occasioned by e ether, which is supposed to be diffused throughout space § *271.); this subtile* and elastic fluid, whose density and elasticity are not uniform or unchangeable, is capable of receiving and transmitting undulatory movements; it is further assumed that when a certain velocity has been attained, the waves of ether, impinging on our eyes, excite the emotion of sight, just as the waves of air excite that of hearing. To explain most of the phenomena of light, reference may be made to others of sound, which exactly resemble them.

This hypothesis was originally founded by *Descartes*, *Huygens*, and *Euler*; and in later times it has been adopted and enlarged by *Young*, *Fresnel*, *Frauenhofer*, *Herschel*, and other philosophers.

The greater number of phenomena may be equally well explained by either theory, yet it must be admitted that some of the more recently discovered properties of light are more satisfactorily accounted for by the second hypothesis, for which reason it now numbers most adherents.

## § 275.

With respect to the production of light, bodies are divided into *luminous* and *non-luminous*.

*Luminous bodies* are those different sources whence light emanates, and which are thus visible of themselves. The greatest permanently luminous body is the *sun*: the *fixed stars* resemble him but in the effects they produce, so far as we are concerned, they are vastly inferior. *Bodies in a state of combustion*, whose efficacy is, however, but transient, are extremely serviceable as sources of light.

According to the corpuscular theory, light issues in an uninterrupted stream from the luminous body; according to the undulatory theory the surface of such a body is set in a state of vibration, and the tremor is communicated to the surrounding ether, resembling in this a sonorous body.

The various luminous bodies which serve as the sources of light may be classed pretty much as follows:—

1°) All those heavenly bodies which shine by their own light; of these, as has been remarked already, the sun is the chief.

2°) *Chemical light*, or that which is obtained by combustion.

3°) *Electric Light*, which under various modifications accompanies the development of electricity; this will be treated of more fully in the section on Electricity.

4°) *Light by Friction*, which is obtained by rubbing together, or striking either similar or dissimilar bodies, (not, however, all bodies without exception,) either *in vacuo*, or in gases, which are not supporters of combustion, or even, according to *Heinrich*, under water and oil; this species of light seems to be of an electrical nature, unless, indeed, it is merely the luminous appearance of the fragments detached from combustible bodies. Similar appearances may be observed in splitting or rending some solid bodies, especially crystals, as well as in the sudden condensation and expansion of gases, and in the sudden and violent compression of liquids.

*Phosphorescent Light* is that which is emitted by many bodies at a low temperature, and is unaccompanied by any essential alteration in their properties; it is so feeble as to be scarcely perceptible except in the dark The luminous appearance of common phosphorus is the result of chemical action, for it obtains only when this substance is in combination with oxygen or chlorine. Of this light there are three kinds:

5) *Phosphorescence by insulation* is a property possessed by many bodies, in consequence of which, after long exposure to the sun's rays, they become luminous in the dark. Wall first discovered this property in the diamond; but it has been subsequently found to exist in several other minerals, especially in certain varieties of fluor-spar. There are also several chemical compounds, as the Bologna Stone and others, which retain for several hours the luminous property they acquire by being insulated. It does not cease even when the phosphorus is immersed in water, or in gases which are not supporters of combustion. These bodies become luminous in the dark, on the application of heat to them. The cause of this phosphorescence is not yet known with any considerable degree of accuracy.

6) *The Phosphorescence of organic remains in a state of decomposition.* The luminous appearance of touch-wood is, perhaps, the most generally known illustration of this property in decayed vegetable matter; the same phenomenon may be observed in animal matter, especially in sea-fish, on which a luminous film is formed. In all these cases phosphorescence seems to be owing to a low sort of combustion, as the emission of light decreases on rarefying the air.

7) *Phosphorescence of organic bodies during life.* The plants which display this light the most conspicuously are the marigold and the yellow lily, a little after sunset, when the atmosphere has been very much heated in July and August; probably it is of an electrical nature. The phosphorescence of many animals, that of most of the infusoria, by which the sea acquires a luminous appearance frequently to a considerable distance, that of many species of zoophytes, mollusca, *crustacea*, and insects, especially that of the *fire-flies, scolopendræ*, and glow-worms, remains problemati-

*In vacuo*, and in all non-respirable gases, it becomes extinct; in oxygen gas it shines with increased brilliancy.

*Non-luminous* bodies are such as become visible only when light falls upon them from some luminous body.

According to the emanation theory, non-luminous bodies become visible in consequence of their reflecting the particles of light which impinge on them; according to the other hypothesis, the waves of ether recoil from the surfaces of these bodies, just as the waves of sound rebound and form an echo. (§ 206.)

The heavenly bodies which shine only by reflected light are the planets, their satellites, and probably, in some degree, the comets also.

## § 276.

Bodies, considered as to their capacity for transmitting light through their substance, are divided into *transparent* and *opaque*.

*Transparent* or *diaphanous bodies* are such as give a free passage to light through the matter of which they are composed, or, in other words, they are such as admit of our seeing other bodies through them with a greater or less degree of distinctness; as instances we may mention the atmosphere, water, and glass.

A perfectly transparent body does not exist, for such a body would allow all the light which falls on it to pass through, and as it reflected none it would itself be invisible. The greater the quantity of light a body transmits and the smaller the portion reflected, the nearer it approaches to perfect transparency. The following experiment will shew this, as to one of this class of bodies.

*First Exp.* Admit a ray of light into a darkened room, and let it fall upon the surface of some water contained in a glass vessel with parallel sides. The ray will pass through the water, but some portion of the light will be evidently reflected from its surface. The same will be observed if for water we substitute a thick plate of glass.

There are many degrees between perfect transparency and absolute opacity, for each of which gradations distinct appellations do not exist; bodies, however, which occupy a mean position between these extremes are said to be *translucent*. They permit the passage of so small a portion of light, that other bodies cannot be seen at all through them, or if seen, but imperfectly; such are foggy air, paper saturated with oil, laminæ of horn, &c.

Some of the most transparent bodies are, the atmosphere on a clear day, a few of the other gases and vapours at a high degree of expansion; most liquids and many solids also are more or less transparent. This property depends, not merely on the absolute transparency of a body, but also on the density of the medium through which the light passes. The thicker any substance is, the less is its transparency. A very thin plate of crown glass would seem to be perfectly transparent, but if several such plates were to be piled one on the other, their transparency would be found to diminish as the number of plates was increased. For a similar reason, distant objects being viewed through a large extent of the atmosphere, are less distinct than those which are near to us. No exact connection has yet been established as existing between the transparency of a body and the material of which it consists. The regularity of its internal structure (§ 88.) and the polish of its surface exert a considerable influence on the capacity of a body for transmitting light; on this account colourless crystals are highly transparent. A remarkable proof of the correctness of the above remarks is furnished by the diamond and common charcoal, as also by the fact that many bodies acquire the property under consideration, if their pores be filled with either oil or water.

*Second Exp.* Ground glass is not transparent, but by pouring oil of turpentine, or indeed any other oil upon it, it is rendered transparent, or at least translucent in a much higher degree. — *Hydrophane.*

*Third Exp.* Two plates of ground glass may be rendered transparent by pouring a little oil of turpentine between the surfaces in contact.

*Opaque* bodies are all such as obstruct the passage of light, nd through which consequently objects are not visible.

It is probable that no body whatever is absolutely opaque, if it e reduced to laminæ of sufficient tenuity, since light is found o pass readily through leaves of gold and other metals.

*Fourth Exp.* If a pane of glass be covered on one side with leaf-gold, objects will be seen through it, and a greenish tinge will be imparted to them.

According to the corpuscular theory, transparent bodies allow a passage more or less free through their substance to the particles of light, and opaque bodies are supposed to be such as light cannot penetrate. According to the undulatory theory, it is assumed that transparent bodies possess the property of transmitting the luminous vibrations of the ether in the same manner as the vibrations of the atmosphere are imparted to solid bodies; the particles of ether that occupy the spaces *between* the atoms of the transparent bodies being *put into a state* of vibration. The degree of a body's transparency is further supposed to depend on the intensity with which this vibratory motion is transmitted on the opposite side of the body. Bodies which are perfectly opaque will by this theory be such as altogether destroy the luminous vibrations of the ether.

## II. THE PROPAGATION OF LIGHT; OPTICS.

### § 277.

Light is propagated in *right lines* from every luminous point in a homogeneous transparent medium, and every such right line proceeding from a luminous point is called a *ray of light.* The following experiments will serve to shew that light is thus propagated:—

*First Exp.* Interpose any opaque object between your eye and the flame of a candle, and the latter will cease to be visible to you.

*Second Exp.* Admit the sun's rays into a darkened room through one or two apertures; the light will appear in the form of straight lines or rays.

Since a luminous point is visible in all directions, we infer that *light is propagated in every direction in divergent rays;* in other words, by *radiation.*

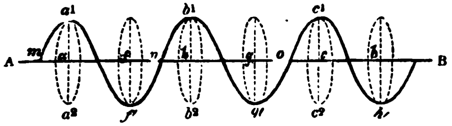
According to the corpuscular theory, light is projected eccentrically from every luminous point, like the radii produced of a sphere, and the term "ray of light" is used to express the direction in which an atom, or a succession of atoms, of this matter, is supposed to move.

According to the undulatory hypothesis, the propagation of light proceeds from every luminous point in all directions, conformably to the laws of undulatory motion. (§ 226.) Every line that can be imagined to be drawn perpendicularly to the surface of a wave of light constitutes a ray, and if such a line be produced until it is terminated in the luminous point, it will give the direction in which the undulations are propagated.

The following explanatory remarks will perhaps render the above condensed account of the undulatory theory, as far as regards the propagation of light, more easy to be understood; they will also serve to shew more plainly the positions occupied by the different particles of ether.

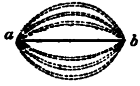
Let us suppose, first, that light is propagated from a luminous body only in the direction of A B, *Fig.* 1; then

*Fig.* 1.



all the particles of ether lying in this path will be put into a state of vibration, the directions in which they move being perpendicular to A B. Let *Fig.* 2 represent a perspective view of the portion *a b* of the ray. This motion of the ether will consequently generate a progressive undulation (§ 212.); the curve *fig.* 1 will represent the situations of the different atoms of ether at any particular moment of their undulation. In the line A B the particle *a* would vibrate constantly in the circle $a^1$ $a^2$; on arriving at $a^1$ its velocity would be *nil;* but as it returned to its original position its velocity increases, until, on reaching *a*, it will have acquired its maximum. In consequence of its inertia, the particle will still move with retarded velocity to $a^2$, at which point its velocity will once more be *nil;* when it will commence its return under circumstances exactly similar to those already described. This vibratory movement of the first particle is not imparted instantaneously, but successively to the other atoms in the direction of the ray. Supposing that all the atoms of ether in the line A B were in a state of repose when *a* began to vibrate, then they would all acquire a similar movement in succession as they were ranged from A to B. Thus, whilst *a* performs one complete oscillation from $a^1$ to $a^2$, and back again to $a^1$, the motion would be imparted to the next atom, *b*, which would begin its first vibration at the very moment that *a* was beginning its second; from that point of time, therefore, *a* and *b* would perform similar vibrations, *i. e.* they would make their excursions in the same directions simultaneously, they would return to their original points, *a* and *b*, together, and would together arrive at their greatest distance from A B. Reasoning in like manner, we may further assume that the particle *c* will commence its first vibration when *b* is beginning its second, and *a* its third, and that from that moment *c* will make corresponding vibrations with *a* and *b;* these consequences may be inferred to apply to all the atoms as far as B, where the ray was supposed to end.

*Fig.* 2.



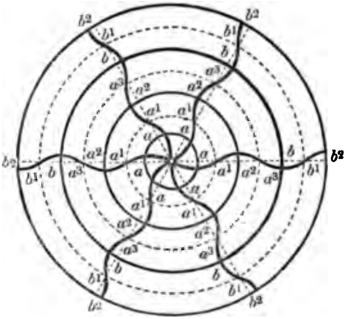
Now, *when all* the atoms of ether composing the line A B *have acquired this* oscillating movement, the equal distances

$a'$ $b'$, or *mn no*, will constitute a ***complete wave.*** All the particles of ether lying exactly between these first-named points, *viz.* *f*, *g*, *h*, which are just ***half a wave*** from the former, are in an opposite state of vibration, so that when *a*, *b*, *c*, *etc.* attain their greatest distance, $a'$, $b'$, $c'$, above A B, *f*, *g*, *h*, will be as far below it at the points $f'$, $g'$, $h'$; all the particles, however, arrive simultaneously at their points of repose, *a*, *b*, *c*, and *f*, *g*, *h*; only it must be borne in mind that they pass each other in opposite directions.

From these considerations, it follows that all the particles of ether in the direction of a ray of light, which are at the distance of 1, 2, 3, 4 . . . *n* waves apart, vibrate with equal velocities in the same direction, but that all which are ½, 1½, 2½, 3½ . . . $n + \frac{1}{2}$, waves apart, move with equal but opposite velocities.

If, now, we further suppose that light is propagated from a luminous point in a plane in all directions, with equal force and velocity, it is clear that we shall have a system of circular waves, resembling that which obtains in non-elastic fluids (§ 216). *Fig.* 3 will be a tolerably accurate representation of such a system. The particles of ether in all the rays which proceed from the luminous point A and at equal distances from A will be in the same state of vibration, as has been already shewn in *Fig.* 1, and as is now represented in the circular waves *a a a* . . . $a^1$ $a^1$ $a^1$ . . . $a^2$ $a^2$ $a^2$ $a^3$ $a^3$ $a^3$ . . . *b b b* . . . $b^1$ $b^1$ $b^1$ . . . $b^2$ $b^2$ $b^2$ . . . &c.

*Fig.* 3.

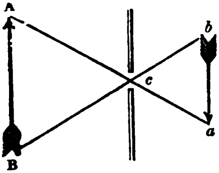


But it has been already stated that light is propagated in *all* directions; in order, therefore, to obtain an accurate idea of the radiation of light, we must conceive the circular waves *Fig.* 3 to revolve about one of their diameters as an axis, so as to generate spherical waves, in which all the atoms of ether vibrate equally.

### § 278.

The *Camera Obscura* (an invention of Porta's, in the middle of e 16th century) acts on the principle that light is propagated right lines. This instrument consists of a darkened chamber, to which the rays of light, from an illuminated object, are aditted by means of a small aperture; these rays are received on a white screen, and thus every point of the object forms a ure coloured with its appropriate tint, the figure being of the me shape as the aperture. These figures, combined, form an verted image of the object.

*Fig.* 4.



Let A B *Fig.* 4 be the object from which the rays pass through the aperture *c* into the darkened chamber, and are received on a vertical wall; the ray of light A *c*, which descends from the head of the arrow, will produce the image of the head at *a*; whilst the ray B *c* from B ascends through *c* and depicts the feather at the top of the image. In like manner, the rays from all the intermediate points between A and B pass through *c* and impinge upon the wall at different points between *a* and *b*, so as to form altogether the line *a b*, which is necessarily an inverted image of A B.

*Exp.* Darken a room completely, and make a small hole in the window-shutter, so as to admit the light from external objects, and they will be depicted on the wall opposite to the opening; it will be better still if a white screen be placed at some distance from the wall, as the objects will in that case retain their natural colours; on whichever surface the images are received they will necessarily be inverted. The smaller the opening the more clearly will the outline of the object be defined; the light will, however, be proportionably lessened. As the size of the aperture is enlarged the brightness of the picture will be increased, but the distinctness of its outline will be diminished in the same ratio; and, lastly, the proportions of the image are increased the greater its distance from the aperture which admits the light. All these modifications are easily explicable from what has been already said with regard to the formation of these images in the § above.

## § 279.

If an opaque body be enlightened on one side only, the side hich is more remote from the source of light will continue dark, nd beyond it there will be a space not affected by the light; this *nstitutes the shadow* of the opaque body: if any object intercept this is seen that side of it which is next to the opaque body will be darkened by the projection of the shadow upon it.

If the light proceeded from a single point we should obtain the boundary line of a body's shadow by drawing right lines from this luminous point to every point in the boundary lines of the body's figure and then producing them. The lines thus drawn from the luminous point to the object would be divergent rays, and the space they contain on the farther side of the body would be its shadow.

If the object have a curved boundary the shadow will be a truncated cone, *fig.* 5.; if its boundary be rectilinear, the shadow will be a truncated pyramid, *fig.* 6.

*Fig.* 5.

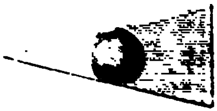
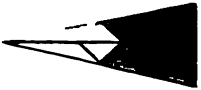
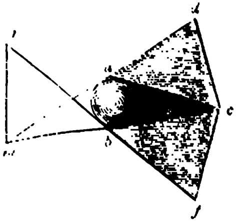


*Fig.* 6.



If the luminous body, as in fact is always the case, consists not of one but of many luminous points, then the space behind the opaque object will contain two shadows, *viz.* the *umbra*, which is perfectly dark, and the *penumbra*, which is partially illuminated, and which is blended off by imperceptible degrees till it arrives at perfect light. For instance, let *l m*, *fig.* 7., represent the luminous body or line from which the light proceeds, and let *a b* be the opaque object which it illuminates, then the umbra will be the space contained between the lines *l a c* and *m b c*, on both sides of which are the penumbræ, between *a c*, and *a d*, and *b c*, and *b f*.

*Fig.* 7.



Construction of the shadows in geometrical drawings. — Why the sun's rays are assumed to be parallel. — Complex shadows when there are several lamps in a room. — A shadow is invariably darker in proportion as the space by which it is surrounded is strongly illumined; hence the deepest shadow is always bounded by the brightest light. — Day and night upon our earth. — Shadows made by the sun and moon. The effects of the umbra and penumbra in card-board transparencies.

## § 280.

The *degree of illuminating power* possessed by the light which manates from any luminous point depends

1) On the *distance* of the luminous body,
2) on the *absolute intensity* of the luminous body,
3) on the amount of the *absorption* the light suffers in its passage through the particular medium it has to traverse, and
4.) *on the angle at which the rays strike the surface of the object.*

## § 281.

In consequence of the propagation of light by radiation (§ 277.) it necessarily follows that the intensity of the light diminishes as the distance of the luminous body increases: the same law holds good in this instance as in all other cases of effects acting from a entre (such as gravity, § 29., and sound, § 260.), *viz. the intenity of the light diminishes as the square of the distance from the uminous body.*

The general expression of this law will be: $I = \frac{1}{D^2}$, I being the intensity and D the distance from the luminous body.

According to the preceding law, it would require four candles at a distance of two feet, or nine candles at a distance of three feet, to give as bright a light as one candle would afford at the distance of one foot. — If the distances of the planets from the sun be given, and the degree of light enjoyed by our earth be reckoned at unity, we can easily calculate by this law what will be the intensity of the light enjoyed by the other planets (supposing their atmosphere, &c. to resemble that of our earth). These proportions are presented to the eye at a single glance in the following table:—

| Planets ............ | Mercury | Venus | Earth | Mars | Asteroids | Jupiter | Saturn | Uranus |
|---|---|---|---|---|---|---|---|---|
| Distances ......... | 0·4 | 0·7 | 1 | 1·5 | 2·5 | 5 | 10 | 20 |
| Intensity of Light. | 6·25 | 2 | 1 | 0·44 | 0·16 | 0·04 | 0·01 | 0·0025 |

## § 282.

By this law we may also measure the relative illuminating owers of different sources of light: instruments which serve for *is purpose are called Photometers.* Those invented by Rumford proceed thus:—Place the two lights which you desire to compare at equal distances from the open ends of a Ritchie's photometer. Interpose an opaque screen between the instrument and each of the lights: in each screen let there be an aperture of equal size exactly opposite the middle of the flame: the rays of light will therefore be projected from an equal superficies of the two candles, and if their illuminating powers are equal the photometer will be as much enlightened by the one as by the other: if this is not the case, remove the stronger light with its screen, till both surfaces of the photometer seem equally bright. The absolute intensity of the two lights will be as the squares of their distances from the photometer.—Proceed in a similar manner to show that with equal absolute intensities the degree of light enjoyed will vary as the surface of the luminous body. Procure two lamps of equal power and sufficient surface of flame, and also two screens, with apertures of equal diameter, provision being made for enlarging one of the apertures, so that its diameter may be doubled, and that, consequently, the opening in one screen may be made four times as large as that in the other. It will be seen that with equal apertures, at equal distances, the surfaces of the photometer will be equally bright; but if the aperture in one screen be enlarged, the surface opposite to it will be rendered more intensely light. Now, remove that light whose screen has the larger opening until the surfaces of the photometer become equally bright, and you will find that this distance will be exactly double the former: so that, with four times as great a luminous area, we obtain a fourfold intensity of light.

According to the corpuscular theory, the intensity of the light, arising from the two causes named above, depends on the force with which luminous matter is projected from the source of light, and also on the quantity of such matter set in motion: the explanation offered by the other theory is that the intensity of light, like that of sound, is owing to the magnitude of the vibrations excited by the luminous body, and on the mass of ether thus put into a state of luminous undulation. Other things remaining equal, the greater the excursions $a\,a'$, $f\,f'$, $b\,b$, &c. *fig.* 1., made by the atoms of ether, the more intense will be the sensation of light they produce; consequently, such a curve as $a'$, $f'$, $b'$, $g'$, &c. *fig* .1., may serve as a graphic representation of the intensity of light.

The sun produces the strongest light with which we are acquainted on our earth: this is owing both to the great splendour of that luminary and to the extent of his disc.—The great influence which the size of a luminous area exerts on the intensity of the light is familiarly shown in the diminished glare there is in a room when the Venetian blinds are let down; the comparative gloom is owing solely to the smallness of the apertures through which the sun's rays are allowed to pass. The light which approaches most nearly in intensity to that of the sun is that which is given off at the charcoal points of a voltaic battery, and that given by the combustion of lime in oxy-hydrogen gas (Drummond's light). The feeblest light is that of burning hydrogen, that of a spirit lamp, and that of phosphorescent bodies. The very low illuminating power of these last, as compared with the light of the sun, may be shown by the following

*Expt.* Place some hydrogen in a state of combustion, or a spirit lamp, or a phosphorescent body, in the sunshine, and their light will cease to be visible.

If the fixed stars are luminous bodies, like the sun in our system, we may infer that the intensity of their light is little, if at all, inferior to his. Of the fixed stars the brightest is Sirius, and yet in the daytime he is no more visible to us than others of less brilliancy. The cause of this is the immense distance of all these bodies from our planet. Wollaston says, that by photometric experiments he has discovered that it would require 20,000 millions of such stars as Sirius to replace the light afforded by the sun, or that this luminary must be removed 140,000 times further from us than he is at present to reduce his light to that of Sirius. In a similar manner, this philosopher has determined that it would require 5563 wax candles, at the distance of one foot from an object, to produce a light equal to that of the sun; whereas the light of the full moon does not exceed that given by a single wax candle at a distance of 12 feet; whence the light of the full moon is only the $12^2 = 144$*th* part that of a wax candle at the distance of a foot. Again, moonlight is $5563 \times 144 = 801072$ times less than that of the sun.

## § 284.

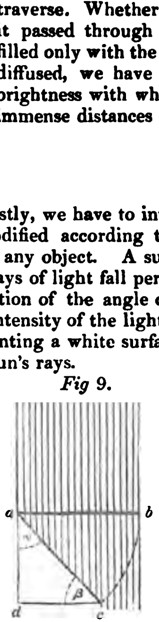
ince no perfectly transparent body exists on our earth
75.), light must necessarily be impaired in its passage
ugh all transparent media, and the diminution it suffers will
as the medium is more or less transparent, and as the pas-
it makes is of greater or less length. The exact ratio in
ch light is diminished, has not yet been determined; it is,
ever, an established fact, that even those bodies which ap-
ach most nearly to perfect transparency, become opaque when
r thickness is considerably increased.

According to Bouguer, the purest sea-water, depth of 730 feet, loses all its transparency, and the sphere in its clearest state would be altogether impervi the sun's rays if it extended rather more than 700 On this principle we can explain the diminished sple of the sun and moon at the time of their rising and sett for the nearer they are to the horizon, the longer is passage and the denser the strata their rays will hav traverse. Whether the light would be similarly diminishe it passed through an absolute vacuum, or through sp filled only with the ether, which is supposed to be universa diffused, we have no means of determining; however, t brightness with which the fixed stars shine, though at su immense distances from us, render this improbable.

## § 285.

Lastly, we have to investigate how much the intensity of light is modified according to the angle at which the rays impinge upon any object. A surface is most strongly illuminated when the rays of light fall perpendicularly upon it; and the greater the deviation of the angle of incidence from a right angle, the less the intensity of the light. This can be experimentally shown by presenting a white surface both perpendicularly and obliquely to the sun's rays.

*Fig* 9.



Let the fine parallel lines *fig.* 9. represent the sun's rays. It is clear that the surface *a b*, on which they fall perpendicularly receives the greatest possible number of rays, whilst any other position of the plane, as *a c*, is impinged on by a smaller number, in fact only by such a number as would have fallen on a plane at right angles to the rays, and having the length *d c*. But *d c* is sin. $\alpha$, the angle of incidence, or cos. $\beta$ the angle formed by the inclination of the plane with a perpendicular to the rays; whence in this case *the intensity of the illumination is as the sine of the angle of incidence of the rays, or, as the cosine of the angle made by the plane with a perpendicular to the rays.*

All that has been established in the preceding § §, with regard to the intensity of light, may now be comprised in the following general formula: —

$$I = \frac{I'\,S.\,\sin.\,\alpha.}{D^2} \text{ or } \frac{I'\,S.\,\cos.\,\beta}{D^2}$$

I being the intensity, I′ the absolute intensity or illuminating power of the luminous body, S the superficies on which the rays fall, D the distance, $\alpha$ their angle of incidence, and $\beta$ the inclination of the plane to a perpendicular to the rays.

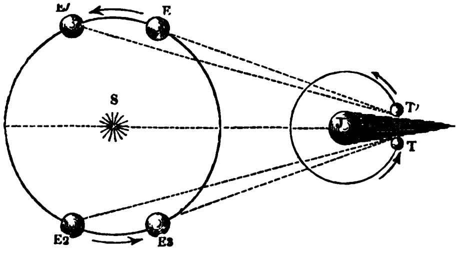
We shall explain presently how these results are affected by the character of a body's surface, and by the material of which it is composed.

### § 286.

Light travels at a prodigious rate; with a velocity, indeed, hich, though it admits of being measured, yet so far exceeds all rrestrial velocities (see Table III. vol. i. p. 26.), that they are arcely comparable with it. It was formerly believed that light oved with an infinite velocity, till, in the year 1676, the Danish tronomer, Olof Römer, found, from observations on the occultaon of one of Jupiter's moons, that light moves through a space about 192,000 miles in a second.

Herschel has calculated that light travels in a vacuum with a uniform velocity of 192,500 miles in a second. This velocity is the same for the waves of light excited by all the heavenly bodies; being in that respect analogous to the waves of sound, which are propagated in the atmosphere with equal velocities, whether the exciting notes be high or low, loud or weak. (§ 257.)

*Fig.* 10.

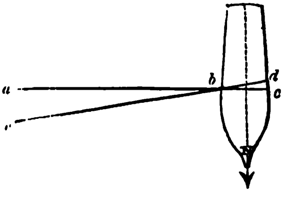


1.) Olof Römer found that when the earth in her orbit receded from Jupiter in a straight line, or in what approximated very nearly to one, as would happen if the earth were at E, *fig.* 10., then the emersion of Jupiter's first satellite T *from the umbra of the* planet J, would be visible about 15 seconds later than we should have expected, from the time the satellite would be occupied in performing that portion of its orbit about its primary. Now this satellite emerges from Jupiter's shadow, in about 42½ hours, or, more exactly, in 42 hrs. 28′ 35″; but in the same time the earth will have moved in her orbit from E to E′, *i. e.* about 2,880,000 miles; but light moves through this space in 15 seconds, consequently it travels with a velocity of 192,000 miles in a second. The converse obtains if the earth approaches Jupiter during the eclipse of the satellite, *i. e.* if she be moving in her orbit from $E^3$ to $E^2$.

Römer's discovery was confirmed by the observations of Dr. Bradley, in 1725, on the *Aberration* of Light. By aberration, we mean the alteration in the apparent positions of all the stars, owing to the velocity with which light moves, and to the motion of the earth in her orbit, in a direction which forms a tangent to the light from the heavenly bodies. In consequence of the aberration resulting from the combined operation of these two velocities, all the fixed stars appear to us to be rather more backward than they really are in the direction of the earth's annual motion.

The following explanation of this phenomenon is given by Eisenlohr, and also by Littrow, in his Die Wunder des Himmels, S. 189. Let M N, *fig.* 11. represent a ship whose side is aimed at point blank by a cannon at *a*. Now, if the vessel were at rest, a ball discharged in this manner would pass through the points *b* and *c*, so that the three points *a*, *b*, and *c* would be all in one straight line; but if the vessel itself move from M to N, then the ball which entered at *b* would not come out at the opposite point *c*, but at some other point *d* as much nearer to the stern as is equal to the distance gone over by the vessel from M towards N, during the passage of the ball through her. The lines *b c* and *b d*, therefore, form an angle at *b*, whose magnitude depends on the position of *b c* and *b d*; the greater the velocity of the ball as compared with that of the ship, the less the angle. Next, for the ship substitute in your mind the earth; and for the cannon, any one of the fixed stars. Let the velocity *b c* of the cannon-ball now stand for that of light, and let *d e* be the velocity of the

*Fig.* 11.



earth in her orbit, the angle $dbc$ is called the *angle of aberration*. This angle has been found to be the same for all the fixed stars, *viz.* 20 seconds, or with greater accuracy 20·25 seconds; whence it appears that light travels with equal velocity through space from all these bodies. If now we suppose $\angle bcd$ to be a right angle, then

$$\text{tan. } \angle b : cd = \text{rad. } : cb;$$

that is,

$$\tan \angle \text{ aberr. } : \text{ veloc. of earth} = \text{rad. } : \text{ veloc. of light};$$

or,

$$\text{tan. } \angle 20{\cdot}25'' : 18{\cdot}963 = 10 : 195{,}000;$$

a result not materially different from that already obtained. This agreement in results arrived at by methods so dissimilar, proves both the accuracy of astronomical observations, and confirms us in the belief of the earth's revolution about the sun.

Light, at its mean velocity, takes about 8 minutes 13 seconds to come from the sun to our earth, and 2⅔ hours to travel from Uranus to our planet. It would require more than 6 years for light to traverse the space betwixt us and the nearest of the fixed stars; hence it follows that we never see these bodies in their actual position. The following illustrations may serve to give a comparative view of the velocity of light and that of other bodies:— A cannon-ball moving with a uniform velocity of 2450 feet in a second, would be 6⅓ years, and sound would be 14 years, in coming to us from the sun; a cannon-ball moving with the same velocity as we have already supposed, would be 16 hours in travelling round the circumference of our earth, a space which light traverses in ⅛th of a second: the velocity of light must therefore be ½ a million times greater than that of a cannon-ball, and more than a million times that of sound. At the rate of about 4 miles in 3½ minutes, being the speed at which Brunel, in 1841, travelled on the Great Western Railway, it would require more than 137 years to go from our earth to the sun.

## III. CATOPTRICS, OR THE REFLECTION OF LIGHT.

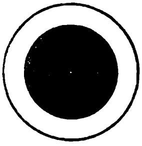
### § 287.

All opaque bodies possess the property of reflecting, to a greater or less degree, the light which falls upon them; they would not be visible to us, as has been observed already (§ 274.), were it not for their reflecting power.

*The smaller the* quantity of light any body throws back, the darker it appears to us; white surfaces reflect most light, and black the least. If a substance were absolutely black, it would not reflect any light at all, and would consequently be invisible to us; experience assures us that no such body exists.

*Expt.* Black velvet is one of the darkest substances with which we are acquainted, and one which seems to reflect no light. Blacken the inside of a tube, and look through it at a piece of black velvet; place over one of the ends of your tube a glass on which an opaque substance is fixed so as to leave only a small transparent ring, *fig.* 12. The light reflected from the velvet, will fall on the eye of the observer, showing that the material is not absolutely black, or incapable of reflecting the rays of light; for in that case the annular aperture would have been equally invisible with the opaque plate in the middle; this, however, is not the fact, and the surface of the velvet, instead of being black, has a greyish tint.

*Fig* 12.



§ 288.

If bodies have rough and uneven surfaces, the light which falls upon them will be *dispersed*, or irregularly reflected, by which means the surfaces thus impinged on by the light, will be rendered visible in all directions. If, on the contrary, the object be one presenting a smooth or polished surface to the rays of light which fall upon it, then, in this case, they will be reflected regularly; and when we look at such an object we shall see, not the object itself, but merely the image of the body by whose rays it is enlightened. Bodies which possess this property in a high degree are called *mirrors*, or *specula*.

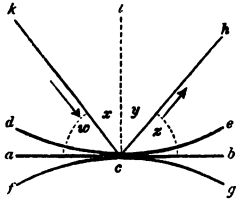
Specula are either *natural* or *artificial*; as instances of the former class we may mention the surfaces of liquids in a state of rest, which are indeed the most perfect specula that can be obtained; many crystals are also natural specula. Artificial specula are made either of metal or glass; the best metallic mirrors are made of platina, or an alloy of copper, silver, and zinc. Highly polished glass plates, blackened on one side, are found to answer well as specula for many purposes, so also are plates of obsidian or volcanic glass if one of their surfaces be well polished. Our common looking-glasses, which are covered on one side with an amalgam of tin, in order to form a reflecting surface, have this disadvantage, that we obtain a double reflection, one from the outer face of the glass, and a second from the metallic surface beneath.

Artificial mirrors are divided, according to the form of their surfaces, into *plane*, *convex*, and *concave*; according to the nature of the curve, they may be either *spherical*, *parabolic*, or *elliptical*; mirrors, with mixed surfaces, are either *cylindrical* or *conical*.

## § 289.

The following are the laws which obtain equally in the reflection of the rays of light from plane and from curved mirrors.

*Fig.* 13.



$lc$, Perpendicular to the plane.
$x$, Angle of incidence.
$y$, " reflection.
$x = y$
$w = z$

Let $a\,c\,b$, *fig.* 13, be the section of a plane speculum, and $d\,c\,e$, $f\,c\,g$ be sections of a concave and convex mirror, which both touch $a\,b$ in $c$; let $k\,c$ be a ray of light impinging on these surfaces, $c\,h$ a ray reflected, and $l\,c$ the *normal* or perpendicular. Experience has shown that

1.) The normal, the incident, and the reflected rays all lie in the same plane, called the *plane of reflection*; and that it is at right angles to the reflecting superficies.

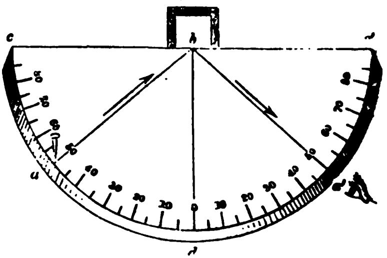
2.) *The angle of Incidence* $x$, and *the angle of Reflection* $y$, are equal, and they are on opposite sides of the normal; hence the incident and reflected rays form equal angles with the plane; and every ray falling perpendicularly on a mirror will be reflected back again on its own path.

3.) The reflection from concave and convex specula takes place as if the rays were received on a plane surface, standing as a tangent to the curve at the point where the normal touches the curve.

These laws may be verified by means of a very simple reflector.

*First Expt.* $c\,a\,a'\,c'$ *fig.* 14 is a semi-circular board, graduated at the circumference; at the centre b, place a small

*Fig.* 14.



looking-glass, vertically to the board; *d b* will then be the normal to the point *b*. Now, set up some luminous point (a common needle will do) at *a*, some 50° from *d*, and the ray *a b* will be reflected to $a'$, just 50° on the other side of *d*, parallel to the circular plane; from this point only would an observer be able to see the image of the object in the mirror.

*Second Expt.* Admit a ray of sun-light through a small aperture in the shutter into a darkened room, in such a manner that the light may fall upon a looking-glass. The whole course of the incident and reflected rays will be plainly marked on the particles of dust, which are illuminated by the sun, and thus experimentally confirm the truth of the law.

According to the corpuscular theory, the reflection of light obeys the same laws as regulate the impact of elastic bodies (§ 110), light, according to this hypothesis, being eminently elastic. The other explanation is, that the propagation of light takes place from every luminous point, by means of the undulatory movements of the ether: on this hypothesis the waves of light follow the general laws of the reflection of all elastic fluids; and, accordingly, every wave from every point, when it impinges on any resisting object so as to be reflected, forms a new wave in its course back, having its centre as much on the other side of the obstacle as the centre of the original wave was on this side; in the case of light, the centre of the original wave is obviously the luminous point. (Compare with this Echo, or the Reflection of Sound, §§ 218. 227.)

### A. REFLECTION FROM PLANE MIRRORS.

### § 290.

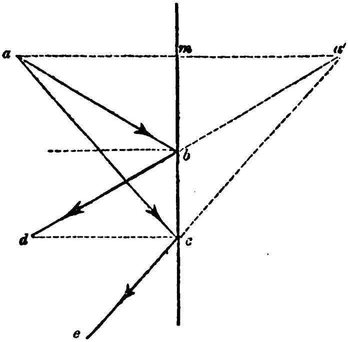
Agreeably to the laws of reflection, laid down in the preceding ection, all the rays of light which fall upon any plane mirror, will be reflected in the same direction as that in which they impinged upon its surface; parallel rays of light will therefore continue parallel to each other after reflection; divergent and convergent rays will diverge and converge respectively with angles equal to their angles of incidence.

The accuracy of these observations may easily be shown by a diagram drawn according to the laws given above.

*Expt.* Admit two parallel rays into a darkened room, so as to fall upon a plane mirror. They will be reflected from its surface in directions parallel to each other; if the rays be convergent, the reflex rays will intersect before the mirror; if they be divergent, they will be reflected so as to recede the one from the other.

All the rays from any radiating point that fall upon a plane irror, are reflected from its surface in such a manner that they em as if they proceeded from a point beyond the mirror; this oint will be situated exactly where the reflected rays, if produced, would intersect each other, and it will be found to be as r beyond the mirror as the radiating point is before it; this oint is called the *virtual focus.*

*Fig.* 15.



Let $m\,c$, *fig.* 15, be the vertical section of a plane mirror, $a$ a luminous point before it, $a\,b$ and $a\,c$ two rays proceeding from it; $b\,d$ will be the reflected ray of $a\,b$, and $c\,e$ that of $a\,c$. Produce $d\,b$, $e\,c$, on the other side of the mirror, and these lines will meet in $a'$; $a'$ is the virtual focus; and from the similarity of the $\Delta$ s, $a\,b\,m$, $a'\,b\,m$, and $a\,c\,m$ and $a'\,c\,m$ respectively, it follows at once that $a'\,m = a\,m$.

According to the undulatory theory, $a'$ is the centre of the reflected waves of light.

The image of any object, which may be regarded as merely the sum of its radiating points, will be as far behind a plane mirror as the object itself is before it; the size and form of the image will correspond exactly with the size and form of the object, with this difference only—that whatever is on the right side of the original will appear on the left in its image, and *vice versâ.*

The reversed appearance of any object seen in a plane mirror, is most strikingly illustrated, by holding a sheet of print or manuscript before such a mirror.

If a plane mirror be placed in a vertical position, then every object it reflects will be accurately portrayed, as regards its situation with respect to the horizon. If a plane mirror be inclined at any angle to an object, the object will appear behind the mirror inclined at an equal but opposite angle; consequently, an object lying flat will appear to stand perpendicularly if a mirror be placed at an angle of 45° to it; and conversely, an upright object will seem to lie down.—All these phenomena are well known, and may be easily verified by diagrams in which the laws of reflection are attended to, and experimentally by using a common looking-glass. — The *Polemoscope* is a perspective glass, having a reflector placed at an angle of 45° to its axis.—Mode of using this instrument. — If any one stands on a plane mirror, his feet and the feet of the image have their soles touching; if the mirror be held above the head, the figure will be inverted in that direction. — The reflection of objects in standing water presents us with similarly inverted pictures.

On this law of the reflection of plane mirrors depends the construction of several optical instruments; as, for instance, the *Heliostat*, the *Helioscope*, and the different kinds of *Goniometers.*

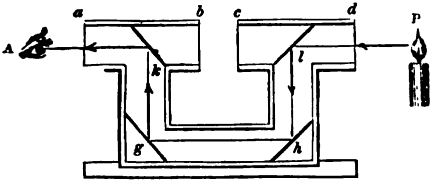
## § 291.

Further, the image produced by the first reflection may be reflected again by one or more mirrors. The image of an object, by this repeated reflection, becomes shifted in every direction, and may be multiplied many times by means of inclined mirrors placed opposite to each other.

To this property of light are owing:—1.) The effects produced by the various kinds of magical perspective. These phenomena are owing to the parallel combinations of several plane mirrors at angles of 45° to the light which falls upon them.

*First Expt.* *Fig.* 16 is a sectional view of a magic per-

*Fig.* 16.



spective, by means of which objects may be seen, notwithstanding the interposition of a board, or other opaque screen, between the eye and the object.

*a b c d* is the perspective tube through which the observer is to look; it is divided at *b c*, so that a board, or any similar obstacle, may be interposed; notwithstanding which an eye at A will distinctly see any object at P.

The apparatus is thus constructed:—At *k* and *l* there are openings in the tube, by means of which a communication is established throughout the hollow pipe *k g h l*. At *k*, *g*, *h*, and *l*, looking-glasses are placed at angles of 45°. The line drawn in the interior of the tube represents the course of the reflected ray; the eye at A sees the object in the mirror, *k*, in the direction of A *k*, or A P.

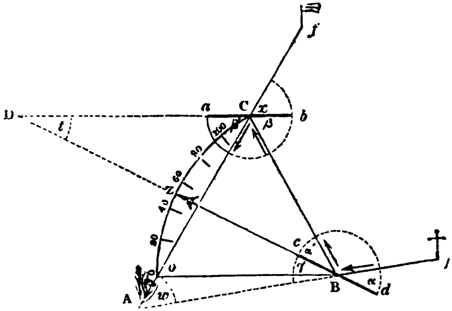
2.) If an object be placed between two plane mirrors, forming any angle whatever with each other, then the image will be repeated as many times *minus* 1, as the angle made by the two planes is contained in 360°, *i. e.* putting *n* for the number of degrees contained in the angle, the number of images will be $\frac{360}{n} - 1$.

*Second Expt.* The *Kaleidoscope* invented by Sir. D. Brewster, is a well-known piece of apparatus; it consists of a tube about 10 inches long, and from 2 to 3 inches wide, blackened inside. Two or three pieces of looking-glass run through it lengthwise, generally forming angles of 60°. One end of the tube is closed by a piece of common glass, on it is fitted a continuation of the tube, the end of this additional piece being closed with ground glass; the space between these two glasses which is about $\frac{1}{4}$ of an inch, is filled with transparent coloured objects, pieces of coloured glass, and the like. The other end of the tube is also covered with a cap having a small aperture through which to look. If the tube be held with the ground glass end toward the light, and the eye be applied to the small aperture, the objects lying between the angles of the reflectors will be reflected five times, and the image of a regular hexagonal star will be formed.

*Third Expt.* Place two inclined mirrors on the drawing of a bastion, and you will have an image of a polygonal fortification.

3.) The application and use of *Sextants* and of Douglas's *Reflecting Circle:*—Both instruments serve, by means of two mirrors, one of which is moveable, to measure the angle made by two objects with the station of the observer.

*Fig.* 17.



The mirror *ab*, *fig.* 17. is fixed, but the mirror *cd* is moveable about B, and when in the position *o* B, it is parallel to the first mirror *ab*, and an arc that shall be drawn with B as its centre between the planes *b* D, B *o*, (the mirrors produced), would be the sixth part of a circle, whence the name of the instrument, the Sextant, is derived; the angle C B *o*, consequently, contains 60°. The side of the mirror *cd* is perpendicular to the index B Z; so, when the latter is moved from *o* towards C, the former is turned about its pivot B; and the index will show, on the graduated arc, the number of degrees contained in the angle *o* B Z, *i. e.* the magnitude of the angle generated by the motion of *cd* from its original position.

Now suppose *dc* and *ba*, the planes of the mirrors, to be produced to D, the point of their intersection, then the angle *t* will mark the degree of their inclination; but as D C is parallel to B*o*, it follows that the angle *c* B *o* must be equal to the angle *t*, and can therefore be used equally with it to mark the inclination of the planes.

If we wish to measure from any station A, the angle which two objects, *g* and *f*, make with A, that is to determine the magnitude of the angle *w*, we should move the mirror *cd*, by means of the index BZ, until we brought it into such a position, that, whilst the eye at *o* sees the object *f* in the direction *o*C, the object *f* should also be seen in the mirror *ab* simultaneously with it, and in the same direction, its image having been reflected as shown by the lines $\gamma$ BC*o*; then in

$$\triangle CDB, \angle t = \angle \beta - \alpha'$$

$$\text{and in } \triangle CBA, \angle w = \angle(\beta + x) - (\alpha' + \gamma).$$

Now, by the laws of Reflection:

$$\angle \alpha' = \angle \alpha \text{ in like manner } \angle \beta = \angle \beta'$$

$$\text{but (Eucl. I. 15.) } \underline{\angle \alpha = \angle \gamma} \;\; . \; . \; . \; . \; . \; \underline{\angle \beta' = \angle x}$$

$$\text{whence } \angle \alpha' = \angle \gamma \text{ and } \qquad \angle \beta = \angle x;$$

whence it follows that,

$$\angle w = \angle 2\beta - \angle 2\alpha',$$

$$\text{and as } \angle t = \angle \beta - \angle \alpha'$$

$\angle w = \angle 2t$, or $\angle 2$ZB*o*; so the angle ZB*o* shown by the index, will be half the required angle *w*. In order to obtain the magnitude of angle *w* at once, without further computation, the arc of the sextant is divided into 120 parts, each of which expresses one degree of the angle *w*.

4.) The effects of mirrors hung parallel to each other in rooms: If an object stands between two looking-glasses hung parallel to each other, an image will appear as far behind each of the glasses as the object itself is before them. Each of these reflections produces a corresponding image in the opposite mirror, and so the object would be repeated *ad infinitum*, were not a portion of light absorbed with each successive reflection.

## B. REFLECTION FROM CONCAVE AND CONVEX MIRRORS.

### § 292.

By *spherical mirrors* are to be understood such as are segments of a sphere; if their concavity be polished, they are called *concave* mirrors; if they reflect from their convex side, they are called *convex* mirrors.

In mirrors of this kind, *figs.* 18 and 19, *c*, the centre of that sphere of which the speculum is a segment, is called the *geometrical centre*, or the *centre of curvature*; whereas *v*, that point in the mirror's surface which is equidistant from all parts of its circum-

*Fig.* 18.

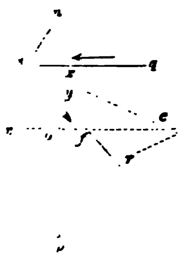
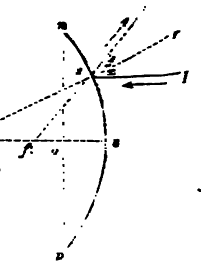


*Fig.* 19.



*f*, Focus.
*v f*, Focal distance.
*c*, Geometrical centre.
*v*, Optical centre, or vertex.
*v c*, **Axis of the mirror.**
*c s*, **Radius of mirror.**
*r c s*, **Principal ray.**
$x = y$.

ference, is called the ***optical centre*** or ***vertex*** **of the mirror.** A right line *v c*, of unlimited length passing through these two centres is the *axis* of the mirror. All the radii of the sphere, as *c v*, *c s*, &c., are also *radii of the mirror's curvature;* and as they are perpendicular to the spherical surface, they, in fact, constitute the normals of the rays which fall on the points *v*, *s*, &c. of the mirror (§ 289.) Every ray from a luminous point *r* passing through the centre of curvature, as *r c s*, *r s c*, is termed a *principal ray.*

The reflection of light from every point of a spherical speculum obeys the universal law of reflection (§ 289.), that *the path of any reflected wave may be found, by assuming that the angle of reflection equals the angle of incidence.*

> For instance, let *q s* be a ray impinging at *s* on the concave speculum, *fig* 18., and on the convex speculum, *fig.* 19., then in both cases *s f* will be the reflected ray, if $y = x$.

### § 293.

The rays of light will be variously reflected from the surface of a concave mirror, according to the direction in which they impinge upon it:

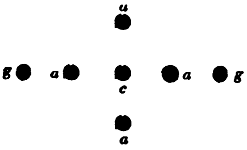
1.) All the rays that fall on a concave mirror in a direction parallel to its axis, will be reflected, so that each of them after reflection intersects the axis. If these rays be very near to the axis, they will cut it after reflection, in a point midway between the optical and geometrical centres, as appears from the construction of *fig.* 20. The point *f* is called the *focus*, and its *distance f v, from* the vertex of the speculum, is called the focal

20.

[illegible]

apertures *g*; some arrangement must be

*Fig.* 22.



and closi
sure. Th
pass thro
will be pa
Now, pla
in such
ray trans
shall imp
*v*, see *fig.*
perpendicular to it; next, open success
and each of the rays passing through
reflected as to intersect the axis *cv*, in th
indeed, the rays will form a pyramid, w
the speculum, and whose vertex is at *f*.
light through the holes *g*, which are mo
axis; and it will be found that their rays
nearer to its boundary, will be so thrown
the axis somewhere between the focus an
mirror. If it is wished to give very g
the individual rays of sun-light, they ma
through the smoke of a chafing-dish.

*Second Expt.* A cylindrical mirror will
calculated to display the caustic curve; it
semi-cylinder, and may be conveniently
polished tin, or of a pretty wide piece
spring, held in form by a semi-circular b
white paper. If the speculum be prese
the sun or to those of a candle, a lumi
visible on the paper, bounded by a line re
in *fig.* 21.

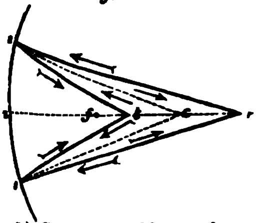
If a parabolic curve be imparted to t
brightest speck will be at its focus, when
will proceed resembling a star.

2.) All diverging rays from a radiant poi
focus of a concave mirror, will be reflected f
directions parallel to each other, and to th
that their distance shall not exceed 10° or 15
Such reflected rays will consequently not inter

This is merely the converse of the pr
truth of it will be at once seen on referrin

3.) All rays proceeding from the centre
which pass through such centre, that is to say
rays, fall perpendicularly on the surface of the
therefore reflected to the centre.

*Fig.* 23.

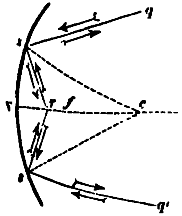


4.) Rays on the contrary, which come from any point, as r, *fig.* 23, beyond the centre of curvature, or which cross the axis at a point beyond such centre, will be reflected so as to cut the axis somewhere, as e. g. in t, between the focus and the centre of curvature.

5.) Conversely, if rays intersect the axis at any point t, *fig.* 23, between the focus and the centre of curvature of a concave speculum, then they will be reflected so as to cut the axis again in another point, beyond such centre. See the direction of the arrows in *fig.* 23.

6.) Lastly, all rays coming from any point r, *fig.* 24, between the mirror and the focus, will be reflected from its surface so as to diverge from the axis.

*Fig.* 24.

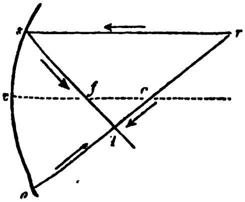


## § 294.

If there be any radiant point before a mirror, the virtual focus of that point may be found (§ 290.) by producing the reflected rays until they meet.

If, then, we are able to determine where two reflected rays will intersect each other, we can at once ascertain the situation of the virtual focus. From every radiant point there proceeds an infinite number of rays, but of these, two only are, for the most part, made use of, in determining the situation of the virtual focus; they are one principal ray, which is reflected on its own path, and one of the rays parallel to the axis, which, when reflected, passes through the focus. The intersection of these two rays gives the virtual focus required.

*Fig.* 25.



It is not absolutely necessary to use a ray parallel to the axis: any other will do, only it must be observed that its reflected ray cannot be determined so easily as that of a parallel ray.

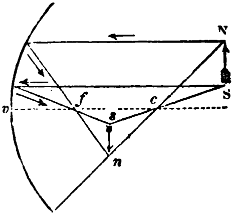
Let o s, *fig.* 25, be a concave mirror, and r any radiating point before it; draw *s q* through the focus *f*, as the reflected ray to *r s;* and from *r* draw *r o*, through the centre of curvature; *q*, the point of intersection of these two rays, is the virtual focus of *r*. The virtual focus of every luminous point in the axis of a concave mirror will be in the axis; and that of any point on one side of the axis, will be found on the opposite side of it.

To determine the situation of the image of an object reflected by a concave mirror, we must find the virtual foci of the points in the object's boundary.

## § 295.

The following are the phenomena presented to us by the r flection of the rays of light which impinge on concave mirrors:

*Fig.* 26.

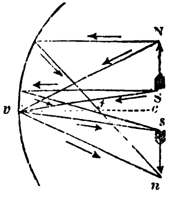


1.) The image of an obj very remote from the mirror, that of the sun, will be in focus of the mirror, and the im will be extremely small.

2.) Every object which is a distance from the mirror grea than its centre, produces an ima between this point and the foc smaller than the object itself, a in an inverted position. (S *fig.* 26.)

3.) If the object be at a distance from the mirror equal to t length of its radius, as N S, *fig.* then the image *n s* will be at an eq distance from the mirror; its dim sions will be the same as those of t object, but its position will be invert as is shown in *fig.* 27.

*Fig.* 27.



4.) If the object be between the fo and the centre of curvature, as *n s* in 26, then the image will be inverted, a its size will much exceed that of the obje its place, also, will be beyond the g metric centre, as N S.

These four varieties of inverted images, produced by t reflection of the rays of light from concave mirrors, are sometin called *physical spectra.*

The existence and position of these spectra may easily shown experimentally, thus:—

*Expt.* Hold a candle opposite to a concave mirror at the distances named respectively in paragraphs 1.), 2.), 3.), 4.) on the preceding page. The spectrum can in each case be received on a white screen, which must be placed at the prescribed distance from the mirror.

Application of these spectra in different optical instruments, as reflecting telescopes, &c.

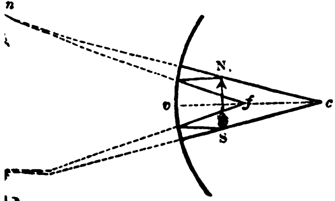
5.) If a luminous body, as, for instance, the flame of an Argand lamp, or a burning coal, be placed in the focus of a concave mirror, no image will be produced, but the whole surface of the mirror will be illuminated, because (2. § 293.) it reflects in parallel lines all the rays of light that fall upon it.

This may be made the subject of an experiment so simple as not to require any further explanation.

Practical application of this fact, in the *reflectors* of microscopes, magic lanterns, and lighthouses, by means of which the light given by the luminous body is increased and transmitted in some particular direction that may be desired.

6.) Lastly, place the object between the mirror and the focus, N S, *fig.* 28, and the image of the object will be behind the mirror; it will not be inverted, but its proportions will be enlarged according to the proximity of the object to the focus. In this case the reflected rays (5. § 293.) diverge, and consequently intersect behind the mirror, so that they appear as if they proceeded from these points of intersection. *Fig.* 28 will illustrate these remarks.

*Fig.* 28.



The truth of this last proposition admits of being experimentally tested.

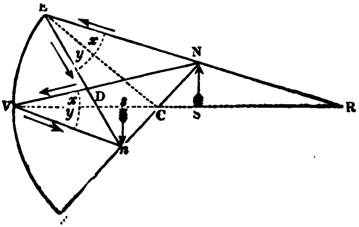
Concave mirrors, from the property last-named, are sometimes called *magnifying mirrors*; and because, by collecting the sun's rays into a focus, they produce a strong heat, they are called *burning mirrors*.

[We shall now proceed to give a simple demonstration of what has been advanced in the present and two preceding §§.

Let F E, *Fig.* 29, be a sectional view of a concave mirror, V its vertex; C the centre of the circle; C V, C E, $CF = r$ radii of the mirror. Let R be any radiant point in the axis, $RV = a$, *its distance* from the vertex. Let R E be an

incident ray, E D the reflected ray, and V D$=a$ t
distance.

*Fig.* 29.



$$\text{Since } \angle x = \angle y,$$
$$\therefore \mathrm{ED} : \mathrm{ER} = \mathrm{CD} : \mathrm{CR}, \qquad [\text{Eucl.}$$
$$\text{and if } \angle \mathrm{VRE} \text{ be very small,}$$
$$\therefore \mathrm{RE} = \mathrm{RV} = \mathrm{a} \text{ nearly,}$$
$$\text{and } \mathrm{ED} = \mathrm{VD} = a \text{ nearly}$$
$$\therefore \mathrm{VD} : \mathrm{VR} = \mathrm{CV} - \mathrm{VD} : \mathrm{VR} - \mathrm{VC},$$
$$\text{or } a : \mathrm{a} = r - a : \mathrm{a} - r;$$
$$\therefore a\,\mathrm{a} - a\,r = \mathrm{a}\,r - \mathrm{a}\,a,$$
$$\therefore 2\,a\,\mathrm{a} = \mathrm{a}\,r + a\,r;$$
$$\therefore \frac{2}{r} = \frac{1}{\mathrm{a}} + \frac{1}{a}. \qquad \text{(I.)}$$

Let $\mathrm{a} = \infty$, *i.e.* let the distance of the radiant poi
infinite, or, in other words, let the rays be parallel; $\frac{1}{\mathrm{a}}$ vanishes, and there remains

$$\frac{2}{r} = \frac{1}{a}$$

$$\text{or } \frac{r}{2} = a = f,$$

that is, the focus $f$ lies in the middle of the radius; and t
fore equation (I.) becomes

$$\frac{1}{f} = \frac{1}{\mathrm{a}} + \frac{1}{a} \qquad \text{(II.)}$$

If the radiant point R lie out of the axis, as at
position may be determined by knowing its abscissa V
and its ordinate S N$=b$.

Let the rays from N make with the axis a very
angle, then their focus *n*, will be given by the follo

uations: —for, let $Vs=a$, $sn=\beta$

$$1.)\ \frac{1}{f}=\frac{1}{\mathrm{a}}+\frac{1}{a}.$$

$$2.)\ \beta=\frac{a}{\mathrm{a}}\cdot b.$$

For, produce the ray EN till it meets the axis in R; hen VD is the focal distance of the point R, and by equa-ion (II.) we have

$$\frac{1}{f}=\frac{1}{\mathrm{a}}+\frac{1}{a}=\frac{1}{VR}+\frac{1}{VD} \qquad \text{(A.)}$$

Now, if we consider VE to be so small an arc that it may e assumed as a right line, and

$$\because \triangle\text{s, } VED, \text{ and } Dsn, \text{ are sim.}$$

$$\therefore VE : VD = sn : sD$$

$$= \beta : a - VD;$$

$$\therefore VE.a - VE.VD = \beta.VD,$$

$$\therefore VD = \frac{a.VE}{\beta + VE},$$

$$\therefore \frac{1}{VD} = \frac{\beta}{a.VE} + \frac{1}{a}.$$

Again, $\because \triangle$ s, VER, and SNR are sim.

$$\therefore VE : VR = SN : SR,$$

$$= b : VR - \mathrm{a},$$

$$\therefore VE.VR - VE.\mathrm{a} = b.VR,$$

$$\therefore VR = \frac{\mathrm{a}.VE}{VE - b},$$

$$\therefore \frac{1}{VR} = \frac{1}{\mathrm{a}} - \frac{b}{\mathrm{a}.VE}.$$

Substituting these values in equation (A.), we have

$$\frac{1}{f} = \frac{1}{\mathrm{a}} - \frac{b}{\mathrm{a}.VE} + \frac{\beta}{a.VE} + \frac{1}{a}$$

$$= \frac{1}{\mathrm{a}} + \frac{1}{a} + \frac{1}{VE}\left(\frac{\beta}{a} - \frac{b}{\mathrm{a}}\right). \qquad \text{(B.)}$$

And since $\triangle$ s, VSN, and $Vsn$, are sim.

$$\therefore ns : Vs = NS : VS,$$

$$\text{or } \beta : a = b : \mathrm{a},$$

$$\therefore \beta = \frac{a}{\mathrm{a}} \cdot b, \text{ which is equation 2.)}$$

$$\text{and } \because \frac{\beta}{a} = \frac{b}{\mathrm{a}}$$

$$\therefore \frac{\beta}{a} - \frac{b}{\mathrm{a}} = 0;$$

The same mathematical deductions hold good for n of this class as for concave mirrors (§ 295.), observin; that in this case $r$ is *negative:*

$$-\frac{2}{r}=\frac{1}{\mathrm{a}}+\frac{1}{a},$$

and

$$-\frac{1}{f}=\frac{1}{\mathrm{a}}+\frac{1}{r}.$$

1.) When $\mathrm{a}=\infty$, *i. e.* when an object is at an infinit tance from the mirror $a=-f$.

2.) If $\mathrm{a}$ diminishes, $a$ must diminish also; thus, wher

$$a=-\frac{r}{3}.$$

3.) When $\mathrm{a}=0$, $a=0$; *i. e.* the object and its imag fall together on the mirror.

## § 297.

*Cylindrical* and *Conical mirrors* act like plane ones i direction of their axis, but in a direction perpendicular t axis they act like spherical mirrors. If such a mirror be p vertically, the image of any object will be of the same len the original; but its breadth will be exaggerated or red according as the convex or concave surface is polished. mirror be laid horizontally, these circumstances will be reve

A conical mirror differs from a cylinder in this, that its s in the direction perpendicular to the axis, consists of an i number of spherical mirrors, of gradually decreasing sizes to the vertex; whereas, in the cylinder, planes passing throug axis and parallel to the horizon, would give equal circles thr out. If such a mirror be placed in a vertical position, an seen in it would appear of its natural length, but its b would gradually taper off towards the vertex.

From what has been just stated it is evident, that these m do not represent objects in their natural proportions; if, fore, any object appears in such a mirror to be of its just d sions, the original drawing must have been distorted acc to regular laws, in order to produce this effect; these pictu well as their reflected images in the mirrors are termed *ca anamorphôses.*

## § 298.

It has been already (§ 287.) remarked, that all bodies wh reflect more or less of the light which falls upon them. means of Ritchie's Photometer (§ 282.) we can compa ities of the incident and of the reflected light. It has been ained that the intensity of light reflected perpendicularly a metallic speculum is about $\frac{2}{3}$, from mercury $\frac{1}{2}$, from $\frac{1}{55}$, and from glass $\frac{1}{40}$ that of incident light; and that roportion becomes less, the more oblique the angle at which ays fall. This diminution of the light is owing to its ab- tion by the reflecting body: from these considerations it ws that metallic specula are the best reflectors.

## IV. THE REFRACTION OF LIGHT.—DIOPTRICS.

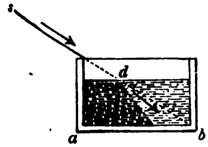
### § 299.

When a ray of light passes out of one transparent medium into nother, either differently constituted, or of a density differing rom that of the former, then the ray will either continue its course in the same path as before, or it will travel in a new direction. If it impinge perpendicularly on the plane by which the medium is bounded, its direction will not be altered; if, on the contrary, it strikes the plane at any other than a right angle, t will be diverted from its original course. This deflection of he rays of light is termed *Refraction*.

*First Expt.* Admit a ray of sun-light in such a manner into a darkened room that it may fall obliquely on a cubical piece of glass; a piece of plate glass will do if of sufficient thickness. The direction of the ray will be changed on its entering the glass.

*Second Expt.* Let a shadow of the width *a b*, *fig.* 32, fall on the bottom of any opaque vessel. Fill the vessel with water, and the shadow will acquire the tapering form represented in the cut, in consequence of the ray *s b* being refracted at *d* towards *c*.

*Fig.* 32.



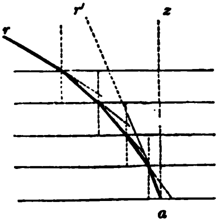
A similar result will be obtained by placing a thick glass plate at the bottom of a square box.

*Third Expt.* Lay a coin, or any similar bright substance, at the bottom of an opaque vessel, as an earthenware basin, and place the whole at such a distance that the edge of the vessel just hides the piece of money from your view, Pour in water, or lay a bit of thick plate glass, upon the coin and it will again become visible.

## § 303.

If several transparent media are arranged in paral one above another in the order of their refractive po most powerfully refractive being the lowest; then a ra falling perpendicularly up will not have its direction but if a ray come obliquely, drawn more and more tow vertical line in each succes tum, as is shown in *fig.* 41. eye situated at *a*, the radi *r* would not appear in its t ation, but at *r′*, which may by drawing a tangent to t from *a*.

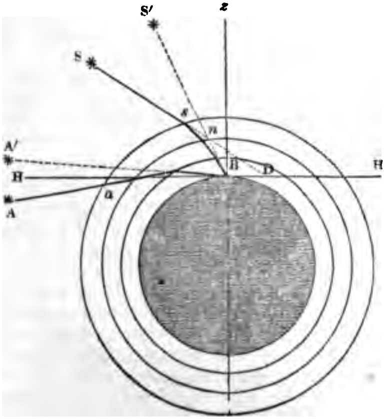
*Fig.* 41.



Now, as we know (§ 198.), that the strata of our at are of increasing density as they approach the earth's s follows that every ray of light falling obliquely on the atr must describe a curve somewhat resembling the above. fact depend the phenomena of *astrononomical* and *terrestr* *tion*, as also do those instances of *unusual refraction* that observed at different times, and which are known as *Mir* *Morgana*, &c.

*Astronomical refraction* is caused by the rays of li the heavenly bodies falling upon our atmosphere,

*Fig.* 42.



quence of which no stars appear to us in their true places, except such as are exactly in our zenith; all others are more or less elevated, according as they are more or less near to the horizon; nay, they even seem to be above it after they have set. — Let the dark circle in *fig.* 42 represent our earth, and the concentric circles around it various strata of our atmosphere, whose densities decrease as their distance from the earth increases. Suppose an observer to stand at B; then *z* will be his zenith, H B H′ his horizon, S any star, S B *z* its true zenith-distance, and S B H its true altitude above the horizon. But in consequence of the refraction of this star's rays in their passage through our atmosphere, as shown by the broken line S *s* B, it will appear to an observer at B to be at S′, *i. e.* at less than its true distance from the zenith. Produce the original direction of the ray S *s* so that it may cut the apparent ray S′B in *n*; then the angle B *n* D formed by these two lines, is the aberration of the star S, or the refraction of its rays for the apparent zenith-distance *z* B S′, at which it is seen by the observer at B. Tables have been constructed by which for any observed zenith-distance the refraction can be found, which will give the true zenith-distance. The greater this becomes, the greater also is the refraction, until for stars in the horizon it reaches the maximum, when it is about 33′. This *horizontal refraction* has the effect of elevating to or above the horizon such stars as are depressed below it. — Referring still to the same diagram, let A be any star below the horizon B H of an observer at B; on account of the rectilinear propagation of light the star would be invisible, were it not that on the rays A *a* falling on the atmosphere at *a* they become refracted in the curve *a* B, so that the spectator sees the star in the direction of the last tangent to the curve, *i. e.* it will appear to him at the altitude H B A′ above the horizon. — One consequence of this atmospheric refraction is, that the sun rises earlier and sets later than he otherwise would, by which means our day is both advanced and prolonged. In central Europe the longest day is thus lengthened about 8·5 minutes, and in the polar regions the sun's stay above the horizon is lengthened by a month. Again, in sultry weather, in the mornings and evenings the lower strata of air cool rapidly, whilst the upper suffer but a small change in temperature; in consequence of this the discs of the sun and moon appear flattened, so that their horizontal diameter considerably exceeds the vertical; this phenomenon is owing to the fact that the refraction diminishes with the height, the lower portions of these luminaries are consequently more refracted than the upper.

Since refraction affects the position not only of
heavenly bodies which lie beyond the limits of our a
sphere, but as all objects in it are also influenced in like ma
we speak of its operations on them as the effects of *terre*
*refraction*, one consequence of which is that distant ob
(such especially as are in or near the horizon), hills, t
buildings, &c., seem higher than they really are, and o
sionally become visible from an opposite coast, when t
great distance and the curvature of the sea's surface pre
their being seen under ordinary circumstances. The di
ence between this apparent and the true height of any ob
above the horizon, or the difference between the angl
these two altitudes, is the magnitude of the terres
refraction.

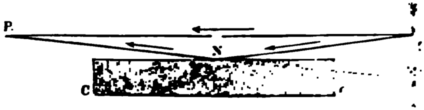
Neither astronomical nor terrestrial refraction are al
equal, as they depend on the density of the strata compo
the atmosphere; and from causes which have been notice
the earlier part of this work, we know that the den
varies. For this reason the measurement of celestial
tudes, as well as that of the heights of terrestrial object
greatly embarrassed when considerable nicety is required,
the results obtained are consequently unsatisfactory.

Nearly connected with that property of the atmosp
we have just noticed, is the unusual refraction someti
called the *Mirage*. In this phenomenon distant obj
which ordinarily are not visible, appear to float in the
and frequently inverted images of them are seen immedi
below the spectra of the objects themselves, thus presen
a striking resemblance to the reflection of objects in w
This unusual refraction frequently happens when t
intervenes between the spectator and the objects a l
expanse of smooth water, as on the Oldenburg coast of
North Sea, where it is called *Kimmung*, or as at the st
of Messina, between Sicily and Italy, where the nam
Fata Morgana has been given to the same natural ph
menon. Scoresby has mentioned several instances in w
he observed it in his voyages on the coast of Greenlan
1822. It has been noticed likewise on extensive plain
the steppes and deserts of Asia and Africa, in which
quarter of the world it was taken notice of frequently by
French army, in Lower Egypt, in 1798-1799. These e
ordinary spectacles are not always to be seen; they
monly happen towards evening, after a close and sultry
when the air is in a calm state, so that the different s
can arrange themselves according to their densities,
when a wind arises the phenomenon ceases. These a
pictures are supposed to be caused partly by the refracti

the rays of light, and partly by their reflection when they fall upon a stratum much rarer than that through which they first passed. See the 5th Law of Reflection § [illegible].

*Expt.* A result closely resembling the effects of unusual atmospheric refraction, may be obtained thus —C C, *fig.* 43, is a box of sheet iron, about 30 inches long, 6 or 7 inches

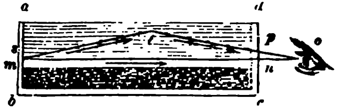
*Fig.* 43.



high, and of about the same width. Fill it with hot charcoal and place it on a level with the eye of an observer: a red hot poker may be substituted for the iron box. Look along the heated surface at some object M which is not at too great a distance, and you will see a direct image of it in the direction PM and an inverted one in the direction PM′. The second image is evidently caused by the reflection of the rays of light at N, from the heated and rarefied air that surrounds the sides of the box, and not by reflection from the iron.

An analogous phenomenon may be produced by arranging liquids of different densities one above another. Pour some water into a glass vessel *a b c d*, *fig.* 44, to the height *m n*. then add a solution of Glauber's salts, or common salt, which must be carefully poured through a funnel with a very small mouth, and whose end reaches to the bottom of the vessel, so as not to agitate the water. By this means we obtain a fluid whose density decreases upwards. Stick a strip of paper on which a word is printed at *s*; and by looking at *o* on the opposite side, and at an equal height with *s*, the word will be seen in its natural position, by means of the ray *o s*; and again an inverted image of it will be visible in the direction *o t* in the higher and rarer stratum of fluid, in consequence of the reflection of the oblique ray *s t*.

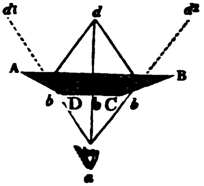
*Fig.* 44.



## § 304.

When a ray of light passes through a medium bounded by parallel *superficies, as e. g.* a plate of glass, and surrounded by a faces. The rays *d b* from a luminous object at *d* v ted in passing throu so that an eye placed they meet, would see t one direct at *d*, and fraction at $d^1$, $d^2$.

*Fig.* 48.



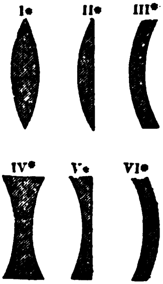
The *Dioptric Anan* pend on this species c They are pictures v viewed through a ki plying glass, present images very unlike themselves.

## B. *Refraction in Glasses having Curved Surfaces, i. e*

### § 307.

Glasses, one or both of whose surfaces are spheric constitute segments of spheres, are termed *Lenses :* two principal kinds, *convex* and *concave, fig.* 49. C have either both sides convex, I*, and are termed *d* or they have one side plane and the other convex, *convex ;* or one side convex and the other concave, that the two surfaces, if continued, would meet), an *menisci*. Concave lenses are *double-convex ;* or V*, *plano-conc* *concavo-convex*, the concavity e convexity.

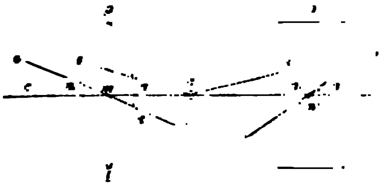
*Fig.* 49.



Lenses III* and VI* *periscopic* lenses ; when t and convex surfaces are act as plane glasses.

Lenses are usually ma but sometimes, for various polished rock crystals a stones. Hollow glasses, v vening space is filled with of high refracting power times substituted for len glass.

Fig. 5[illegible].



The point *c*, *fig.* 5[illegible], is called the *geometric centre* or *centre of curvature* of a lens; *p q* is the *diameter* or *linear aperture*, and *n*, its middle point, is the *optical centre*. A straight line drawn through *n*, at right angles to the diameter, is termed the *axis*; *o* and *i* are the *vertices* of the lens. Radii, as *c a*, *c a*, being at right angles to the curved surfaces, constitute *perpendiculars* for every point of incidence of a ray of light. A *principal ray* is one which passes through the optical centre, as *l n o*.

§ 308.

If we conceive planes to be so placed as to touch all the lenses at the points *a a*, it is evident that such planes must be at right angles to the axes, and consequently parallel to each other; but if planes touch the surface of a lens at any other two points either above or below the axis, such planes will cut each other, and their angle of intersection will be greater as their points of contact approach the rim of the lens. Hence all lenses in the refraction of light act like prisms formed by the two touching planes, which we have imagined to be placed on the surface of the glass at the points of a ray's incidence and emergence. They therefore resemble a combination of an infinite number of prisms with varying angles of refraction, or multiplying glasses with an infinite number of refracting surfaces. Since every ray of light which passes through a prism, is refracted towards the thicker part (§ 305.) of the prism, it follows that convex lenses will refract rays towards the axis, and concave lenses will refract them from the axis.

§ 309.

After the explanation just given as to the general principle on which lenses act, we shall be able easily to determine, by means of the laws of refraction (§ 300.), what path a ray will pursue on its emergence *from the glass*.

small distance through them: they are also termed *b* *glasses*, because when the sun's rays are brought to a after passing through a lens of this kind, they prod strong heat.

If the phenomena which have been just explained abo compared with those produced by concave mirrors, § 295., i be found that precisely the same effects follow the refracti light through convex lenses, as attended its reflection from co mirrors.

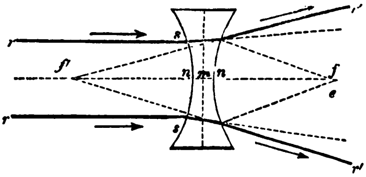
### § 312.

In the refraction of rays through *concave lenses*, we obs that—

1.) A ray falling on the lens, in the direction of its axis, p through without suffering refraction; every principal ray, continues its course without changing its direction. Com § 307. and *fig*. 50.

2.) The direction of all other rays is changed by refract and after emergence from the lens, their divergence increases

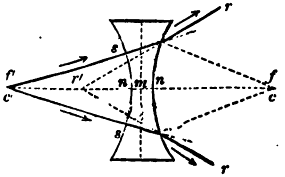
*Fig*. 57.



3.) Rays near to the axis, and parallel to it, diverge after re tion, and appear, if produced, to come from a *virtual focus*, shown in *fig*. 57.

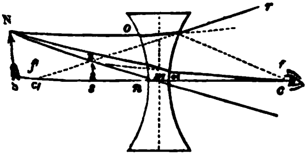
4.) Divergent rays from any point in the axis, diverge more widely after refraction, and seem as if they came fr point nearer to the surface of the lens than that from which actually proceed; in *fig*. the rays from $f'$ are refra towards $r$, and appear to proceeded from $r'$.

*Fig*. 58.



5.) As concave lenses not bring the rays which refract to a focus on the posite side to that on w the object stands, it foll that they do not presen with any aërial image objects, but that we see jects themselves through lenses of this kind, as geometric images, on the further side of the glass. These images are erect, they are invariably less than the objects themselves, and are apparently nearer to the glass. See *fig.* 59. The image of very remote objects is extremely small, and is situated in the virtual focus.

*Fig.* 59.

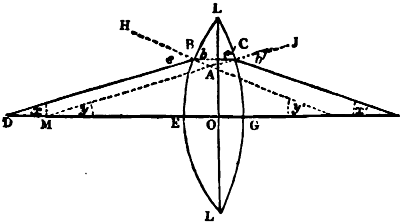


For this reason these lenses are sometimes called *Diminishing Glasses.*

If the reflection of light from convex mirrors (§ 296.) be compared with its refraction through concave lenses, it will be seen that their effects are precisely similar.

[All the phenomena respecting the refraction of light through convex and concave lenses, which we have deduced by construction, agreeably to the universal Law of Reflection (§ 300.), may be inferred and demonstrated geometrically by a process resembling that we have already adopted with regard to spherical mirrors, §§ 295. 296.]

*Fig.* 60.



Let *fig.* 60, L L represent the section of a convex lens, in the direction of its axis D F; let M be the centre of curvature of the face L G L, and M′ that of L E L.

1.) Let D be any radiant point in the axis, and D B an oblique ray from it: then C F will be the ray after refraction, and O F its focal distance = G F nearly, if the thickness of the lens be inconsiderable.

Now let radius M G $= r$, and M′ E $= r'$,

D E $= \rho$, distance of object from lens,

F G $= \alpha$, distance of image from lens,

*H B*, a perpendicular to tangent at B.

$\alpha$ becomes the less also will $\alpha$ be, retaining sign, so that for $a=r$, we have $\alpha=-\frac{r}{2}$; for

$$\alpha=-\frac{r}{3}.$$

e images will invariably fall on the same side ct, between the focus and the lens; they are rtual, and diminished.

no-*convex lenses*, where $r'=\infty$

$$=\frac{1}{\alpha}+\frac{1}{a}$$

lass $n=\frac{3}{2}$

$$=\frac{1}{\alpha}+\frac{1}{a}$$

) $a=\infty$, then $\frac{1}{a}=\frac{1}{2r}$ $\therefore a=2r=f.$

.) $a=2r$, then $\frac{1}{a}=0$, $\therefore a=\infty.$

3.) $a=r$, then $\frac{1}{a}=-\frac{1}{2r}$, $\therefore a=-2r.$

or *plano-convex lenses* the equation is

$$-\frac{1}{2r}=\frac{1}{a}+\frac{1}{a},$$

the other values can be found the same as in C. *concavo-convex glasses* the equations may be deduced he preceding, by making the radius $r$ or $r'$ of the ty negative.]

## V. DOUBLE REFRACTION OF LIGHT.

### § 313.

*refraction* is meant, that property possessed by many bodies, of dividing into two portions such rays of ransmitted through them. Objects viewed through ices consequently appear double.

liar refraction, however, does not obtain in every *which rays may pass* through the transparent body of light striking the face *a d* in the point *m*; *m r* would be its axis, and the ray *l m* would be divided at *m* into the two *m n* and *m p*. The line *m n* is the ray of ordinary refraction; its direction is determined from the index of refraction (§ 300.) according to the ordinary laws of refraction, and it is marked by the dotted line. The line *m p*, on the contrary, is the ray of extraordinary refraction, which is inclined farther from the axis than the other, and is distinguishable from it in the diagram by its having little transverse lines drawn across it. — In calcareous spar the angle *n m p* formed by the divergence of these two rays is 6° 12′ when the ray impinges perpendicularly on the crystal. — On emerging from the face *b c*, both the rays suffer a second refraction, and as the two refracting faces *a d*, *c b* are parallel to each other, they continue in a direction parallel to the incident ray *l m*, and to each other, as *p q* and *n o*.

*Fourth Expt.* Lay a piece of Iceland spar with its natural face over a black point printed or written upon a piece of white paper; the point will be seen double in whatever position the crystal may be placed.

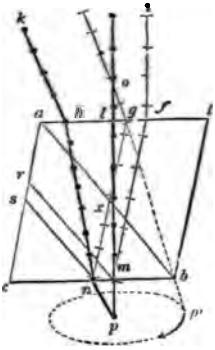
If we look vertically down upon the crystal, both points will be in the diagonal of the obtuse angle, or in the line of the principal section. The point which is nearer to the acute angle of the upper face of the crystal is seen there in consequence of the extraordinary refraction.

If the crystal be turned round over the point whilst the eye is steadily fixed in the same position, the image formed by the extraordinary refraction moves with the principal section about the image which is formed by the ordinary refraction. — Thus it is easy at any time to determine which is the ray of ordinary and which of extraordinary refraction.

*Fifth Expt.* Place one of these crystals with the diagonal of its obtuse angle over a straight line, and but one image will be seen, because both the refractions are in the direction of this line, the observer as in the former case looking perpendicularly down on the spar. Turn the crystal, and two lines will be visible, which will recede from one another until the diagonal cuts the line at right angles, when the image of extraordinary refraction will have attained its maximum distance from the image of ordinary refraction. If the revolution of the crystal be continued, the lines will appear to approach till the diagonal of the principal section again coincides with the line.

*Fig.* 66. will illustrate the production of the double image

*Fig.* 66.

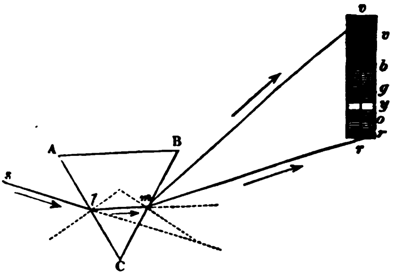


spoken of in the above experiment. Let $adbc$ represent a principal section, and $ab$ its axis. Suppose there to be a point $p$, beneath the face $cb$, observed by an eye above the face $ad$ of the crystal. Now if $pm$ be a ray striking the face $cb$, on entering the crystal it will be divided into the ray of ordinary refraction $ml$, and the extraordinary ray $mf$, which recedes from the axis $mr$. The emergent rays $lo$ and $fi$, which are the continuation of these two refracted rays, are parallel to $pm$ and to each other. Again, let $n$ be a point near to $m$, and let $pn$ be its incident ray: it will also be cleft into the ordinary ray $nh$, and into the extraordinary $ng$, which on emerging from $ad$ will continue in the directions $hk$ and $go$, parallel to $pn$ and to each other. Since the ray of extraordinary refraction forms with the ordinary ray an angle of a few degrees, it is readily perceived that if the points $m$ and $n$ are sufficiently near, the ordinary ray $mlo$ will be cut by the extraordinary $ng$ somewhere between $l$ and $m$; let it then be cut in $x$. But as the emergent ray $lo$ is parallel to $pm$, and $go$ to $pn$, $lo$ and $go$ must intersect each other somewhere beyond $ad$; let them do so in $o$. Now if a spectator stand so that his eye at $o$ shall receive these two rays, he will see the point $p$ by ordinary refraction in the direction $ol$, and by extraordinary refraction in the direction $og$, or at $p'$, that is to say, nearer the acute angle $d$ of the body. If the crystal be made to revolve about the ordinary ray $op$ which goes perpendicularly through it, then the image $p'$ generated by ordinary refraction will move in the same direction as the crystal around $p$.

Of the crystals which possess this property of double refraction, there are many which have only *one axis* of double refraction, as the Iceland spar; others again have *two axes*, which are variously inclined towards each other. To the former class, besides the Iceland spar, there belong rock-crystal, tourmaline, sapphire, ruby, emerald, &c.; to the second class mica, topaz, gypsum, arragonite, nitrate of potash, &c.

In all crystals with only one axis of double refraction, which *for the most* part coincides also with their axis of

*Fig.* 67.



beam through a prism, a stripe of light *r v*, which may be most conveniently received on a white screen, or even upon the wall of the room: the direction of the refracted ray we know from § 305. The ray will also be not merely diverted from its original course, but it will be dispersed or spread out like a fan.

*b.*) This stripe of light is not white, as was the case with the original ray, but coloured, and in fact the six prismatic colours arranged in the order given above, that is to say, the red is nearest the vertex of the prism, and the violet will be the farthest from it; the former is therefore the least, and the latter the most refracted.

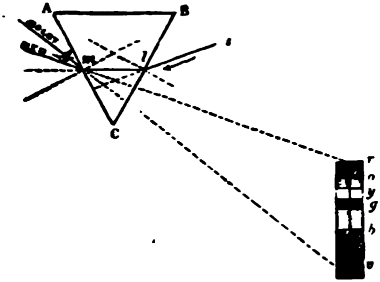
*c.*) If the screen on which the spectrum is received be brought close to the prism, the space *v r* will be coloured only at its extremities *v* and *r*, the intervening space being white. As the screen is removed to a greater distance, the other colours make their appearance until the intermediate space becomes completely coloured.

*d.*) If an object be held in the different coloured rays of the spectrum, it will be evidently illuminated most strongly in the yellow light, and the intensity will diminish as it is moved towards the limits of the spectrum. Words written or printed will therefore be read distinctly in yellow light at a greater distance than when held in light of any other colour.

*Second Expt. Complementary Spectrum produced when any object is viewed through a prism.*

A radiant point seen through a prism is not merely deflected from its position as we have shown (§ 305.), but it *appears in* the form of a straight line lying in the direction

Fig. 68.

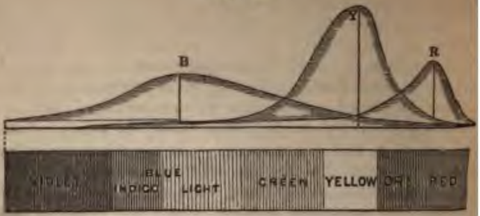


of the plane of refraction; this line is composed of the prismatic colours continuously arranged, but in an inverted order to that which they assumed in the preceding experiment. The violet will now be nearest to the vertex or refracting angle of the prism, and the red will be the farthest from it. It will be seen from *fig.* 68. that this arrangement of the colours must necessarily obtain.

Now if a white screen about two inches in width be the object viewed through the prism, and supposing it to be brought close to the prism, then there will be a column of colour at top and bottom, but all its middle will continue to be white. Increasing the distance of the screen, the next portion to the violet will be changed to blue, and that next to the red will become orange. Removing it still farther from the prism, the coloured portions will increase in width, the white will be completely coloured, and the screen will present a perfect spectrum.

Sir Isaac Newton, who discovered the compound nature of light, by distinguishing the light and dark blue as blue and indigo respectively, made the spectrum to consist of seven colours. If we observe attentively we shall see that the respective colours are not strongly defined, but that the red, by almost imperceptible gradations, is changed into orange, this again, in like manner, is softened off into yellow, the yellow gradually becomes green, the green becomes blue, and this last colour increasing in depth, is at length changed into violet. Hence it has been inferred that the differently coloured rays possess a different degree of refrangibility, increasing from the red to the maximum attained by violet. The coloured stripes in the spectrum are of unequal widths. According to Newton's investigations their respective widths

*Fig.* 74.



"From this view of the constitution of the solar spectr we may draw the following conclusions: —

"1.) *Red*, *yellow*, and *blue* light exist at every point of solar spectrum.

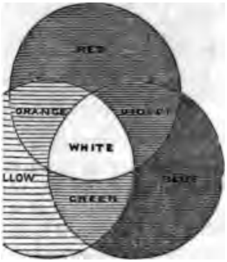
"2.) As a certain portion of *red*, *yellow*, and *blue* con tute *white* light, the colour of every point of the spectr may be considered as consisting of the predominating col at any point mixed with white light. In the red space tl is more red than is necessary to make white light with small portions of yellow and blue which exist there; in yellow space there is more yellow than is necessary to m white light with the red and blue; and in the part of blue space which appears violet there is more red than low; and hence the excess of red forms a violet with blue.

"——— Now, if we suppose that three parts of yel two of red, and one of blue, make white, we shall have colour at Y (*fig.* 74.) equal to 3 + 2 + 1, equal to six par white mixed with 7 parts of yellow; that is, the compo tint at Y will be a bright *yellow*, without any trace of re blue." — The quantity of red light existing in the or may perhaps be equal to 4 parts with 5 parts of yellow, 1 of blue; then, from the preceding explanation, it app that there remain 2 parts of red and 2 of yellow light w combine to form orange. By similar combinations we deduce the origin of the other compound colours in spectrum.

Each of the six prismatic colours has some other called its *com mentary* colour, with which, if it be combined, we shall ob white. The complementary colour to each of the three fu mental colours is the compound colour obtained by mixing other two fundamental ones; and for each of the compo colours, that primary one which does not enter into its com *sition.*

ig. 75 will serve, in a simple manner, to illustrate these rvations. The three circles which intersect each other, so that the circumference of each passes through the centres of the other two, contain the three primary colours—*red*, *yellow*, and *blue*. Where two of these spaces come together, we have the secondary colours —*orange*, *green*, and *violet*. In the middle portion, where the three fundamental colours are combined, we have *white*. The complementary colours are placed in the diagram opposite to each other, sur- ling the white light, to represent its reproduction by ombination of colours.

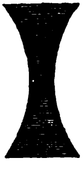
*Fig. 75.*



## § 319.

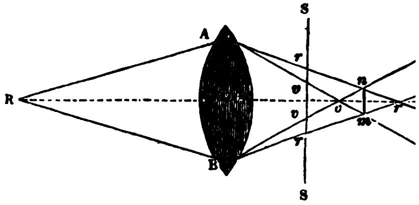
figure presented by a transverse section of a lens be considered, it will be seen that the convex lens tes pretty nearly to what would be formed by placing s, with their bases, one on the other, *fig.* 76. A; and that of the concave lens to the figure made by placing two prisms with their vertices touching each other, *fig.* 76. B, but that in each the angle of refraction is greater towards the edge of the lens.

76.



Rays which are transmitted through these glasses must consequently undergo a prismatic dispersion in addition to their ordinary refraction, and this dispersion will be greater the nearer the rays are to the edge of the lens. One consequence is, that wed through them, and images formed by them, are at their edges, by which they lose in distinctness even by the spherical aberration of the rays of light. (§ 309.) distinct appearance caused by this prismatic colouring he *chromatic aberration* of lenses. It is especially detri- the convex glasses (or object glasses) of telescopes, y are employed for the formation of aërial images of the jects which are viewed through the instrument (vid.

*Fig.* 77.



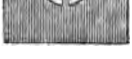
To render this phenomenon, resulting from th
the sun's rays, more intelligible, let R, *fig.* 77. rep
luminous point; every ray in the pencil A R B
from it is not only refracted, but the pencil is dis
the prismatic colours. The most refrangible rays,
meet nearer the glass, at *v*, the red further off, at *r*.
*v* and *r*, where the greatest number of rays meet, i
point, there will be a circle, having a diameter
circle is called the circle of aberration.

*First Expt.* Referring still to *fig.* 77.: interce
which have passed through the convex lens before
at their focus, by placing between the glass and
screen S S of white paper, and on it you will s
white in the middle, around which there will b
yellow, fringed off towards the edge into red.
position of the paper, the red being outermost,
figure.

Next, place the paper beyond the focus at S′
outermost circle will be violet, shaded off into
white in the middle.— In this case, as *fig.* 77.
bounding zone consists of violet rays.

*Second Expt.* To procure the coloured rings d
the preceding experiment perfectly distinct and
the interior white space, cut a ring-shaped hole in
thin card-board or tin, as is shown in *fig.* 78. su
diameter may be rather less th
the lens's circle of aberration m
Hold this screen at the focus,
circle of aberration may fall exa
space within the ring; this
receive all the light, so that no r
transmitted through the apertu
screen be moved in the direction
of the lens, the red will first be
perceived behind it; next, a ye

*Fig.* 78.



and, last of all, a white one, if a second sheet of paper be held beyond that in which the aperture is. In like manner, if the plane be removed beyond the focus, a violet ring will first be visible; next, a blue; and then a white one, as before. — The mode in which these rings are produced is clear from *fig.* 77.

### § 320.

It was an object of considerable importance to discover some means by which this indistinctness of the images, owing to the chromatic aberration of the lenses, might be counteracted. The problem to be solved was therefore, just this, to produce a refraction of the rays of light, which should be unaccompanied with prismatic dispersion. This desirable object was attained by using two substances, which, with nearly equal refractive powers, had very dissimilar dispersive powers. The substances employed were *crown-glass* and *flint-glass*. A prism of the latter kind of glass possesses a much higher dispersive power than a similar prism of crown-glass, but the refraction of the rays is nearly the same in both. Hence it becomes practicable to construct *achromatic or colourless prisms* and *lenses*.

*Crown-glass* is made of flint and alkali only, oxide of lead enters into the composition of *flint-glass*.

According to Dolland's observations, the mean refractive power of flint-glass is to that of crown-glass as 158 : 153; according to Fraunhofer's, 164 : 153 (vid. § 300.); the prismatic dispersion in English flint-glass is 1½ times, but in Fraunhofer's it is twice as great as in crown-glass.

### § 321.

An *achromatic prism* is one through which objects are viewed refracted indeed, so that they are not seen in their true position, but yet free from a prismatic fringe about their edges. They consist of two prisms fitted together, the one being of flint and the other of crown-glass. The vertical angle of the flint-glass prism must be less than that of the crown-glass, and their sizes must be inversely as their dispersive powers.

In English flint-glass the vertical angle of the flint-glass prism must be ⅔ that of the crown-glass, but in Fraunhofer's it must be ½ the size.

tances be closely observed of these bright and dark spo from $p'$ and $p''$, the centres of the respective systems, it wi be seen that the first bright stripes I I are at the distance an entire wave from the line passing through the middle the *fig.*; the next bright stripes I I I I are at a wave length from the former, or of two waves' lengths from th middle line; and so on for all the successive bright strip the distances will be 1, 2, 3, . . . . $n$ waves' length. On th contrary, the lines of interference (marked by the large dots will be at the distance of ½ a wave, 1½ wave, 2½ etc. waves or, expressing it in general terms, those rays of light whic produce interference, or dark stripes, are at the distance ½, 1½, 2½ . . . . $n + \frac{1}{2}$ waves. Lastly, as the length of th undulations differs according to the colour of the ligh (§ 325.), it follows that the distances must also differ; i red light, the light and dark stripes will be almost as fa again from each other as in violet light; in white ligh then, alternations will closely succeed each other, and th stripes will consequently be of the prismatic colours.

## § 327.

The interference of the rays of light is the exciting cause Newton's coloured rings as they are sometimes called; also of t prismatic colours observable in thin fish-scales, in spirit-of-wi if it be made to cover some dark surface in extremely thin fil These colours may also be seen in a drop of oil as it spreads o a surface of water, in pieces of crystal, especially in Iceland sp rock-crystal, &c.; they are visible too in soap-bubbles, in t blown-glass, on the surface of mother-of-pearl, on the wi of many species of insects, &c. These prismatic colours w produced by reflection in the Iris button invented by Barton, entire surface of these buttons being divided into a vast num of fine grooves.

*First Expt.* To produce Newton's coloured rings, obt a flattish convex lens (a watch-glass will do), and a piece common window or plate glass. Press the two steadi together, and luminous rings will be seen about their poi of contact, of the same colour with the incident rays, if th light be homogeneous. These rings are separated from eac other by dark bands, as the light diminishes from the middl of each of the rings. The smaller the waves of light, the les the rings they generate; in violet light they are at a minimum, and in red at a maximum. In reflected light th point of contact is black; in transmitted light it is bright the rings which in reflected light appear luminous, are dark in transmitted, and vice versâ. If white light, or sun-light, be used in this experiment, there will be as many systems of rings as there are colours, in consequence of the unequal lengths of the undulations of the primary colours; these falling partly over one another, produce the compound colours. On comparing the reflected with the transmitted colours, it will be found that the latter are invariably the complementary colours to the former.

*Second Expt.* The spectrum that may be observed in splinters of glass or of crystal, or between the leaves of many crystalline bodies, as *ex. gr.* is common in the gypsum of Montmartre, is strictly analogous to the coloured rings of Newton, only that in these instances the colours are not separated by circular dark spaces, but by very irregular dark lines. — Similar effects may be produced by breathing on two plates of glass, and then pressing them tightly together. These figures will vary considerably in form, and if white light be used in colour also, if on pressing the plates together, one of them be moved along the surface of the other.

*Third Expt.* The spectral colours of a thin film of soap-suds show best in vacuo. Dr. Böttger describes the following mode of performing the experiment: — Put into a common pint bottle of white glass about ¼ of a dram of soap, scraped fine; on which pour about a couple of ounces of distilled water. Heat the bottle carefully, under a constant pressure, over a spirit lamp, till the soap is dissolved in the small quantity of liquid, and its temperature is raised nearly to the boiling point. Then skilfully close the bottle with a cork, which, on account of the rarity of the air within, had better be covered with a coat of sealing wax. Keep it in motion until the temperature sinks to 75° or 80° Fahr., and a bladder of soap will be produced, completely filling the interior of the bottle. The upper segments of the bubble display the most splendid coloured rings, which are produced by the infinitely minute particles of soap extending themselves in thin layers. The bubble may be kept sometimes for several days in the vial, without bursting. Observe that the bottle should not be held quite horizontally, and that the film of soap has not spread itself in a slanting direction, but lengthwise, to obtain the result in perfection. It is but right to add, that a first attempt may not prove successful; but expertness in making the bubble will be acquired with a little practice.

## VIII. PHENOMENA DEPENDING ON THE DIFFRACTION OF LI

### § 328.

The deviation of the rays of light from their rectilinear in passing the boundaries of opaque bodies, so as to cast portion of light on the shadows of objects, is termed the in or *diffraction* of light. If the light be homogeneous, the stripes will be observable among the diffracted homogeneou such stripes being parallel to the sides of the body which ca shadow. If the light be white, the lines will be tinged w prismatic colours.

Grimaldi, of Bologna (1660), was the first who the diffraction of light. In modern times, the subje been investigated, and explained by Fresnel, Frau Herschel, and Schwerd.

Some of the simple phenomena, which are owing diffraction of light, may be verified by the foll experiments: —

*First Expt.* Suspend an opaque black ball in the rays, and the presence of light in the shadow which i will be very perceptible.

*Second Expt.* Hold a bit of fine wire, or a needle, similar object, close to one eye, the other being closed look steadily at it against any light back-ground, as dow, or a candle, and you will see several needles.

*Third Expt.* If sun-light be admitted through narrow crack into an otherwise dark room, several will be visible at some distance from the real one, sep by dark bands from each other.

*Fourth Expt.* Make a rectilinear incision, with a penknife, in a piece of cardboard. Look through the the flame of a candle, and on each side of the real others will be seen parallel to it, and marked with the tral colours. This experiment may be rendered still striking, by looking through the slit in the cardboard, di at a narrow cleft in the shutter by which the sun's ra admitted into a dark room.

Results similar as to colouring and extent, but of g beauty, are obtained by making the light to pass th several apertures, ranged close to one another.

*Fifth Expt.* Look at the flame of a candle throu thinnest part of a feather, and you will see several fla a row: the brightness of their colouring will depend on the intensity of the light.

*Sixth Expt.* Look at any luminous point through a piece of fine cloth, and the light will be obviously inflected in a direction parallel to the texture of the material.

These phenomena can be explained, according to the corpuscular theory, only by calling in the aid of other auxiliary hypotheses with regard to the nature of light; since it is assumed that this diffraction is owing partly to an attraction and partly to a repulsion exerted by bodies on light in its passage past them. This explanation is unsatisfactory, as it fails to account for the origin of the dark intervening spaces.

The undulatory theory, on the other hand, regards all these phenomena as consequent upon the interference of light; and that when the waves of light impinge on solid bodies, they are disposed to propagate new undulations, which start from these points of incidence, and by crossing each other's paths, produce interference. Compare with this §§ 220. 222. 227., and especially what has already been advanced in reference to this subject in § *226*.

## IX. POLARIZATION OF LIGHT.

### § 329.

Light thrown back from reflecting plane surfaces, as well as that which, in its transmission through transparent substances, has undergone either ordinary or double refraction, possesses the following remarkable properties: —

1.) It is not perfectly reflected from a second reflecting plane, in every position in which such plane may be placed.

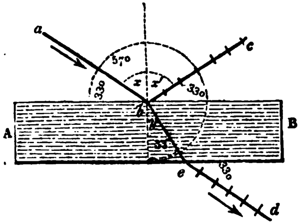
2.) It is not perfectly transmitted through a second transparent body, whatever the position of this second body: and lastly

3.) It is not doubly refracted by a body possessing this peculiarity (§ 313.), in every position that such body may occupy.

Light thus peculiarly reflected, or refracted, is said to be *polarized*.

This effect is produced in its highest degree, that is, light is *perfectly polarized* only when it falls on the reflecting or refracting plane, at some particular angle; which is called the *angle of complete* or *perfect polarization*. It differs, however, according to the nature of the body which causes the reflection, or refraction. According to Brewster, complete polarization obtains only when

*Fig.* 82.



the refracted ray, *b e*, *fig* makes, with the reflecte *b e*, a right angle; so angle *c b e*=90°, and a $x+y=90°$.

According to B ter's law just ref to, it follows that *fig.* 82., be the ang complete polariz $y = 90-x$, and c quently *sin.* $y$ = c

But from (§ 308.) expresses the index of refraction; substitute *cos. x* for *s* and we have $\frac{sin.\ x}{cos.\ x} = tan.\ x$; whence the law expressed bally is, *the tangent of the angle of complete polarizati invariably equal to the index of refraction.*

From these data we can readily determine the ang complete polarization for any substance, if we only kno index of refraction. Thus, *ex. gr.*, according to the tab indices in § 300., the index for atmospheric air is 100, that for glass, 153,200; and for water, 136,600: sequently, the angle of complete polarization for air glass is $tan.\ x = \frac{153200}{100028} = 56°\ 51'$; and for air and v $tan\ x = \frac{136600}{100028} = 48°\ 17'$.

## § 330.

That plane in which a polarized ray is capable of being pletely reflected, or transmitted, at its proper angle of polariz from a second plane which intercepts the ray, is termed its *of polarization.*

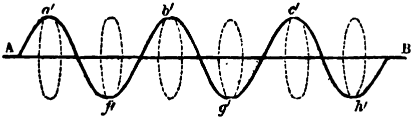
Every ray of polarized light has one plane of polarization reflection, and another for its refraction; and these two plar at right angles to each other: a reflected and a refracted r therefore *polarized at right angles to each other.* If the pla reflection and refraction are perpendicular to the plane of zation of the incident ray, in that case the polarized ray v neither reflected from the transparent body, nor trans through it: the *ray is then said to be polarized in a plane dicular to the planes of reflection and refraction.*

The two rays of a ray divided by double refraction are both polarized; but at right angles to each other. The ray of ordinary refraction lies in the plane of the principal section, whilst the ray of extraordinary refraction is polarized in a plane vertical to the former. (§ 314.).

To explain the causes of the polarization of light is among the greatest difficulties in the whole science of optics. The most simple and satisfactory explanation is that afforded by the undulatory hypothesis. The principal phenomena will be accounted for as we come to them, in accordance with this theory. We may at once explain how the æther is supposed to vibrate in polarized light.

It is assumed, that in non-polarized or common light the particles of æther vibrate every way in the direction in which the waves are propagated (§ 277.), but that in polarized light the motions take place only in two opposite directions. The plane in which these excursions take place is called the *plane of vibration;* if a plane be conceived to be situated at right angles to the plane of vibration, and in the direction of the ray, this will be its *plane of polarization.* Hence it follows that the vibrations of the particles of polarized light take place perpendicularly to the plane of polarization. Let A B, *fig.* 83., be a ray of polarized light, and the surface of the paper its plane of vibration, then the curve $a'f'b'g'c'h'$ will represent the atoms of æther vibrating in this plane at some particular moment, and a plane placed at right angles to the paper in the line A B would be the plane of polarization for that particular ray.

*Fig.* 83.

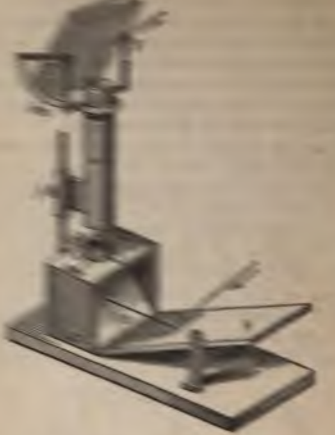


Instruments contrived for the exact and convenient observation of these phenomena and others shortly to be detailed, as also for the measurement of the angle of polarization, are called *polariscopes.* They are variously constructed, but Baumgartner's is, perhaps, among the best for its simplicity, as well as for its convenience and accuracy in the management of observations.

Its construction in the main is, first, a plane mirror *a*, *fig.* 84., of glass, blackened on the back and varnished, which is inclined at an angle of 57° to the horizon; this mirror re-

ceives the light reflected on it by a common looking
at an angle of [illegible]; these rays it polarises and proje

*Fig.* 58.



tically upwards. The polarised ray passes throug
circular aperture *d* up the tube *a*, which is blacken
side, and which may be raised or lowered at pleasure
down the pillar *f*. Over the upper end a ring *h*
which is moveable about an axis, and carries a frame
taining either a blackened glass mirror like the
or else some 10 or 12 glass plates, laid smoothl
upon the other. This frame may be placed at di
angles with the axis of the tube. This part of the app
must be so contrived, that for it we may be able to sub
a crystal of double refraction (an achromatic prism of I
spar is the best), which is set in a ring, and may be
about in the upper opening of the tube. Substances th
which we wish to conduct the polarised ray are lai
glass, set in a ring at *d*, so that they can be turned ab
axis of the polarised ray. An account of Biot's app
will be found in his *Traité de Physique*.

## X. *Reflection and Refraction of Polarized Light.*

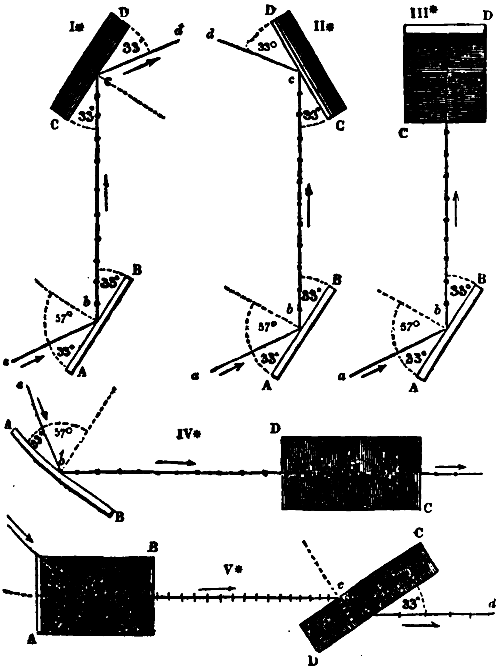
### § 331.

If polarized light be reflected, we shall find

1.) That a ray of light falling under the angle of complete larization on the first polarizing mirror, and being reflected ence, will be completely reflected also from the second mirror, the plane of its incidence against the first mirror coincide with e plane of its reflection from the second.

2.) The second mirror does not reflect the light polarized by e first, when the planes of incidence and reflection are perendicular to each other.

*Fig.* 85.



Let A B, *fig.* 85., be the mirror of polarization, *a b* an ordinary ray incident upon it, and *b c* the polarized ray reflected from it. This ray will be reflected from the second or reflected mirror C D, in the direction *c d*, if C D be parallel to A B as I*, and again when it has been turned 180°, or a half circle from that position as II*. In both cases, according to 1.), the incident, the polarized and reflected rays *a b*, *b c*, and *c d* are in one and the same plane; in fact, according to the diagram in the plane of the paper's superficies.

But if by 2.) the reflecting mirror make an angle of 90° with the mirror of polarization, or if these two cross each other as C D, III* represents, then C D will not throw back the polarized ray *c d*, which falls upon it at *c*, because its plane of reflection, as the drawing shows, stands perpendicular to the surface of the paper. The like result follows from similar causes, if the mirror be turned round 270°.

Hence it follows, that during one entire revolution of the second or reflecting mirror about the polarized ray which falls upon it, it comes into two positions, such that the light thrown on it from the first mirror will be completely reflected, and in two other positions in which the incident ray will be absorbed. If we mark the first position, in whic the mirrors are parallel to each other, and in which complet reflection obtains, with zero, then at 90° from that point th reflection will be *nil*, at 180° it will again be complete, an at 270° again *nil*. In any intermediate position the refle tion will be partial, and the nearer the ray to the angle refraction 90° or 270°, the more feebly is it reflected. A cording to Malus, the intensity of the reflected light is variably proportional to the cosine$^2$ of the angle formed the inclination of the first plane of incidence with second.

If several plates of white glass, laid one on the other, be s stituted for the reflecting mirror, the light polarized by reflect will present the following appearances: —

1.) The light reflected from the first mirror is not transmitt through the glass plates if its plane of refraction coincides with, is parallel to the plane of reflection of the first or polarizi mirror, as C D in *figs.* I* and II*.

2.) The maximum of the light polarized by the first mirror transmitted through the plates of glass, when the plane of its r fraction is perpendicular to the plane of reflection of the fi mirror, *i. e.* when the glass plates have the position C D in I and V*.

Hence it appears, that a ray polarized by reflection is transmitted through glass when its position is such that it cannot reflect the light; and, conversely, that it is not transmitted through the glass plates if it can be reflected from their surface.

## § 332.

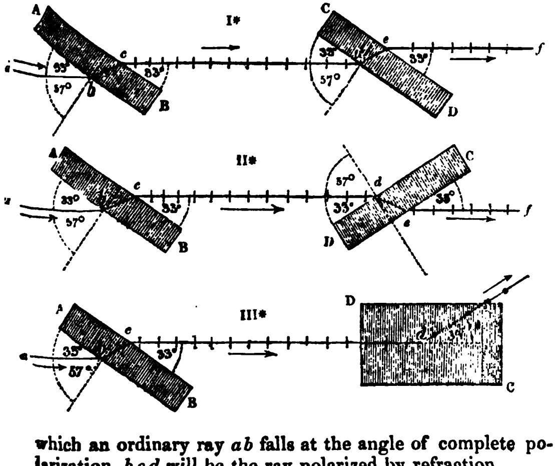
The following are the phenomena to be observed with regard to rays of light polarized by refraction:

1.) Light which has become polarized by passing at the proper angle through several plates of white glass, ranged one upon the other, will be transmitted through a similar system of plates, if the plane of refraction of the first system coincides with that of the second.

2.) Light polarized by the first system does not pass through the second, if the planes of refraction of the two systems of plates stand at right angles to each other.

Let A B, *fig.* 86., be the first system of glass plates, on

*Fig.* 86.



which an ordinary ray *ab* falls at the angle of complete polarization, *b c d will be the* ray polarized by refraction.

In the first case the ray passes through a second system of glass plates C D, if it be parallel, as I*, to A B, or if, as II*, it be turned round 180°, or half a circle. In both cases the planes of refraction of A B and C D coincide, *i. e. b c* and *d e*, with the polarized ray *c d*, lie in the same plane, and in the diagram in the plane of the paper.

But if the second system of glass plates C D be at an angle of 90° to the former, as in III*, then the ray incident at *d* is not transmitted, for its plane of refraction as the figure shows, is perpendicular to the plane of the paper.

Hence we infer, that light polarized by refraction obeys the same laws with regard to a second refraction, as light polarized by reflection did with respect to a second reflection.

In the place of the second system of glass plates put a reflecting mirror; or, if you please, observe the ray reflected from the first glass plate, and you will find that:

1.) The light transmitted through the first system will not be reflected by the second, if the plane of reflection coincide with the plane of refraction, as in positions I* and II*, where the plane of refraction of A B, and that of reflection of C D, are supposed to lie in the surface of the paper, and

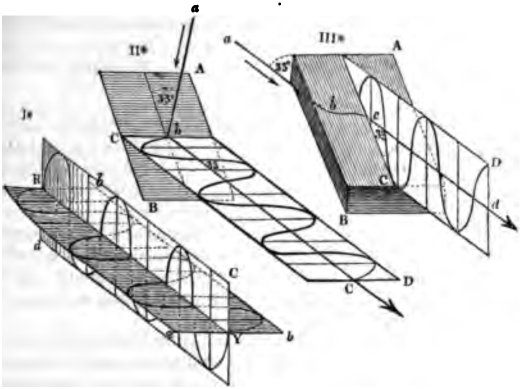
2.) That, on the contrary, the mirror, or the outermost plate of the second system, reflects the ray polarized by the first, if the plane of reflection be at right angles to that of refraction, as C D in III*, the plane of reflection in this case being vertical to the paper.

A similar relation appears to obtain with regard to light polarized by refraction, as we found to exist in that polarized by reflection; since the ray which the first system of plates had polarized will not be reflected from the second, if its position be such as to admit of the transmission of the light; and conversely, that when transmission is impracticable, the ray is reflected; and lastly, that this reflection occurs just at that point in the system of plates at which light, polarized by reflection, would have been transmitted.

From the phenomena respecting the polarization of light by reflection and by refraction, explained in the preceding sections, it is clear that this condition may be induced by two distinct modes; and further, as has been already remarked in § 330., the plane of polarization, and the planes in which the reflected and refracted rays vibrate, are invariably at right angles to each other. Thus, the particles of æther in a ray polarized by reflection vibrate in a plane which stands perpendicularly to the plane of reflection of the first or polarizing mirror; whence the plane of such a ray's polarization and its plane of reflection coincide. The particles of a ray polarized by refraction vibrate in the plane of refraction; and their plane of polarization is vertical to it.

Let R Y, *fig.* 87. I*, be a ray: it will be polarized in the two planes *a a b b* and *c c d d*, which cut each other vertically. Suppose *a a b b* to be the plane of vibration for the ray polarized by reflection; then the serpentine line drawn upon it will be the curve of vibration and intensity of the polarized particles, *c c d d* being their plane of polarization. In like manner, *c c d d* will be the plane of vibration, and *a a b b* that of polarization, for the ray polarized by refraction. If A B, *fig.* 87. II*, be a perspective representation of a polarizing mirror, on which a ray, *a b*, falls at the proper angle; *b c* would be the reflected polarized ray, and C D would be its plane of vibration; the curve which is drawn on it expressing the vibrations of the polarized particles of æther. *Fig.* 87. III* is a similar representation of a refracted polarized ray: A B is the system of glass plates; *a b* the ray incident thereon at the angle of complete polarization; which, being refracted in the direction *b c*, is propagated towards *c d*, as a ray polarized by refraction. The plane C D, at right angles to the glass plates, will be its plane of vibration; and the curved line depicted on it will be the curve in which the polarized particles move.

*Fig.* 87.



Now, as a ray which falls on several plates of glass is *partly reflected and* partly refracted, it is clear that it must

## B. *Chromatic Phenomena attendant on the Polarization of Light.*

### § 334.

If polarized light be transmitted through very thin plates of perfectly crystallized bodies, which have been split or cut in the direction of their primary axis of crystallization, as *ex. gr.*, through leaves of gypsum, or mica; this light, on being polarized a second time, displays new properties; for, on turning round the crystal, or the second mirror of polarization, or the system of glass plates, as the case may be, there will arise an alternation, not merely in the intensity and dimness of the light, but also in its colours.

In all those positions in which the primary section of the crystal forms an angle of 0°, 90°, 180°, and 270°, with the plane of reflection of the first mirror, *i. e.* when the plate of crystal either coincides with the plane of reflection, or is vertical to it, the image or ray appears bright in the second mirror, if it be so situated that its plane of reflection coincides with that of the first mirror. If, on the contrary, the mirrors be so situated that their planes of reflection stand at right angles to each other, then it appears dark in the second mirror, in the same position of its principal section. These phenomena will be reversed, if the light which passes through the plate of crystal fall upon a system of glass plates at the proper angle of polarization; that is to say, it will be dark through the glass plates, if they be placed in such a manner as rendered the second mirror bright; and if they be in that position in which the second mirror was dark, they become bright.

Turn the plate of crystal in its own plane, right or left, around the polarized beam, so that it may occupy a position distinct from those already mentioned, and the most beautiful simple colours will be seen, those of the reflected ray being invariably complementary (§ 318.) to those of the simultaneously transmitted ray. The colours attain their maximum intensity at every half-quarter turn, *i. e.* when the principal section of the crystal deviates 45° from the positions named in the preceding paragraph. If the second polarizing mirror, or system of glass plates, be turned one quadrant from that position in which it showed the colours most brightly, the colours of the reflected and transmitted rays will be exchanged.

From what has been said, it is evident that in one entire revolution of the plate in its plane, and also in one entire revolution of the second mirror, or system of glass plates, the light undergoes eight changes, being most intensely coloured at the octants, but at the quadrants appearing colourless or dim.

Substitute an achromatic prism of Iceland spar for the second mirror, and you will see two images of the plate. If the secons of the plate of crystal and of the Iceland spar lie in the ame plane one above the other, or if they intersect at right ngles, one image is bright and the other dim. If either the hin plate or the spar be made to revolve about the polarized ay, the two images are tinged of the complementary colours; at very quarter turn under 45° the colours acquire their greatest egree of brightness, and when they partially lie over each other hey are white.

These phenomena, as well as others to be mentioned in the following sections, may be most conveniently observed if the fine plate of gypsum, mica, or other transparent crystal be placed on the glass which covers the aperture *d* of the polarization instrument, described in § 330., and turned round with it.

The kind of colour shown by these bodies depends on the thickness of their leaves; at a certain thickness, Biot says about $\frac{1}{30}$th of an inch, they are colourless, the vivacity of the colours increases as the density diminishes, until they are rendered too thin, when the colours again vanish. They appear of a single colour only when the thickness is uniform; if this be unequal the colours also vary. This peculiarity is most evidently displayed in a wedge-shaped polished piece of gypsum, one end of which should be so thick as not to produce any colour, whilst the other end, for an opposite reason, is also destitute of colour; all the colours answering to the different thicknesses of the crystal will be seen in a regular succession of bright and dark stripes, the intensity of the colours increasing in proportion to their nearness to the thin end of the plate.

These phenomena of colours, and especially the last noticed, as also those which will come under our consideration in the succeeding sections, possess a striking analogy with the prismatic rings of Sir I. Newton, described in § 327. The undulatory theory attributes these appearances to the interference of the waves of polarized light, which are retarded in their passage through the fine plate of crystal.

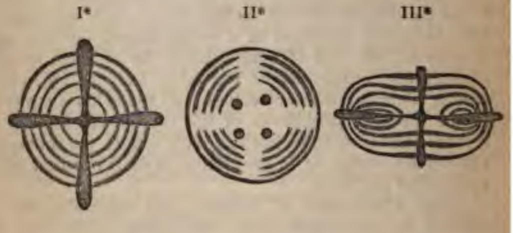
## § 335.

Spectra more beautiful than those we have yet described, characterized too by their possessing definite figures, may be obtained by transmitting the polarized light through a slice of the crystal cut at right angles to its axis, the light being made to pass in the direction of the axis. On the second polarization of the light transmitted through these plates they will exhibit several concentric rings of varied colours, closely resembling

Newton's prismatic rings, and intercepted in the middle b rectangular cross. This cross is either white or black, and rings are always composed of the complementary colours. T cross seen in the second mirror, or through the system of gl plates, will be white, if the mirror or plates be so placed as reflect or transmit the ray polarized by the first mirror; it w be black if the light be absorbed or unable to continue its cour Both the images will be seen simultaneously through an achr matic prism of Iceland spar, which will best display the comp mentary colours of the rings.

Coloured rings are formed about both the axes of su crystals as have two axes, their centres being intersect sometimes by but one straight or curved line, instead of two in the form of a cross.—I* and II*, *fig.* 88., represe the arrangement of the rings in crystals having but a sin axis; III* that which obtains in crystals having two axe

*Fig.* 88.



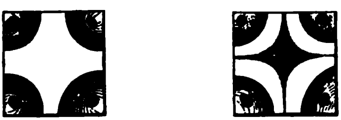
§ 336.

If a polarized beam be transmitted through a transparent u crystallized body, as *ex. gr.* through glass, no such change as have just described occurs in the light. From this fact, as w as from the explanations given in the previous sections, it see that these phenomena are intimately connected with the inter crystalline structure of the transparent medium. If a modi cation be induced in the internal arrangement of these su stances, by the application of heat or pressure, or otherwise, th exhibit chromatic phenomena closely resembling those of cryst line bodies. Professor Seebeck, who discovered this propert has given to the figures thus formed the name of *entoptic colour figures.*

This peculiarity may be rendered permanent in glass by heating it until it becomes soft, and then cooling it quickly in the air.

I* and II*, in *fig.* 89., represent the figures obtained by rapidly cooling a square piece of glass. I*, *fig.* 89., further represents the image depicted on the second mirror of polarization when in the position shown in *fig.* 85. I* and II*, as *fig.* 89. II* does that represented in the position III* of the same *fig.* 85. Thus it is easy to determine what figures belong to light transmitted through the system of glass plates when placed in any of these principal positions.

*Fig.* 89.



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The discovery of the phenomena attendant on the polarization of light as produced by its reflection from glass is due to Malus, 1810; Arago, in 1811, first noticed the peculiarities in the colours of polarized light, since which time these remarkable properties have been investigated by Brewster, Biot, Fresnel, Herschel, Seebeck, and others. The limits within which it is proper that this volume should be kept are too narrow to allow of our entering more fully into the details of these extraordinary phenomena, which have contributed in so high a degree to establish on a firm basis the credibility of the undulatory theory as to the nature of light; we must, therefore, pass over *elliptical* and *circular polarization*, referring the reader for further information on these subjects to the works of Biot, Pouillet, Brewster, Herschel, and others.

## X. OF THE STRUCTURE AND FUNCTIONS OF THE HUMAN EYE.

### § 337.

By the sense of sight, *i.e.* through the medium of nerves formed for that purpose, we are rendered sensible of the *presence* of external objects, and also of their *form*, *colour*, *movement*, *size*, *distance*, and *position*.

"Myopia," or near-sightedness, is that condition of the eye, peculiar to some persons, in consequence of which they see objects distinctly at less than the usual distance of distinct vision; the opposite imperfection is "presbyopia," or far-sight. The subjects of the former infirmity receive no distinct impression of objects beyond the range at which they see distinctly, for the images of such objects fall *in front* of the retina. Far-sighted persons, on the contrary, have no distinct image of objects at a distance of from 8 to 10 inches from the eye, because their image is projected *beyond* the retina. To remedy these natural defects, the latter class should make use of *convex lenses*, by which the rays of light would be brought sooner to a focus, so as to meet on the retina; and the former class should employ *concave* spectacles, by which the rays would be rendered more divergent, and would, consequently, meet on the retina instead of before it.

The principal cause of either long or short sight will be found to be the nature of the employments in which the eyes are principally engaged. If spectacles are used to aid imperfect vision, those ought to be selected which exactly remedy the defect to which the individual is subject. The choice must therefore depend on the distance of distinct vision of the unaided eye, and also that at which it is wished to see objects plainly with the aid of the spectacles. Let $a$ represent the natural distance of vision, and $\alpha$ that which it is wished to attain; then the radius $r$ of the spectacles which would suit the eye would be, if double convex, $\frac{1}{r}=\frac{1}{\alpha}-\frac{1}{a}$ (see § 312. under A 4); or if double concave, $-\frac{1}{r}=-\frac{1}{a}+\frac{1}{\alpha}$ (§ 312. B).

If the distance of distinct vision of a far-sighted person be 12 in., and he wishes by the aid of glasses to see objects distinctly at 8 in., then $\frac{1}{r}=\frac{1}{8}-\frac{1}{12}$, or $r=24$ in.; *i. e.* he must use a double convex lens, having a focal distance of 24 in. — Conversely, if the distance of distinct vision of a near-sighted person be 4 in., and he desires to see objects distinctly at 8 in., $-\frac{1}{r}=-\frac{1}{4}+\frac{1}{8}$, or $r=8$ in., *i. e.* he would require a double concave lens, whose focal distance is 8 inches. Spectacles can, of course, be made to render objects distinctly visible at greater distances, but they are decidedly injurious to the sight. In case such should be required, their radius may be found for any particular distance in the manner shown above.

The inverted image on the retina may be seen by paring off, with a sharp knife or razor, so much of the sclerotica of an ox's eye as renders the remaining portion transparent. Now hold the cornea at a proper distance opposite to any luminous object, as the flame of a candle, and you will have a small inverted image of the flame distinctly visible on the transparent part of the sclerotica.

An artificial glass eye, which may be procured at the opticians, will be found convenient in illustrating the functions performed by the different parts of this organ, as also for showing how convex and concave glasses remedy the opposite defects of long and short sight.

Sometimes the retina becomes partially or entirely insensible to the impressions of light. This morbid condition of the organ is termed *amaurosis*. *Cataract* is another disease to which the eye is liable. It consists in a thickening of the crystalline humour; in consequence of which light is either imperfectly or not at all transmitted to the retina. This disease is cured by couching, *i.e.* either by extracting or depressing the lens, and using very convex glasses to discharge the proper office of the crystalline humour in a healthy state.

## § 346.

To the production of a distinct image on the retina, it is further requisite that it be of a certain magnitude, which will depend on the susceptibility of the eye, and on the illuminating power and colour of the object. The image of an object moderately illuminated must be 0·001 of an inch long, or the extreme rays of light must form an angle of ½ a minute in the eye at a minimum; whence it follows that an object of mean illuminating power will be visible if its distance from us is not more than 68 or 69 thousand times its greatest length. Strongly luminous bodies, such as the fixed stars, are visible at infinitely small visual angles; they excite in the eye merely a sensation of light, without creating any impression as to their apparent magnitude.

Plateau asserts that white may be distinctly seen in the light of the sun at an angle of 12″, yellow at one of 13″, red at 23″, and blue at 26″; but that in ordinary day-light these angles must be ½ as large again.

## § 347.

Light must act upon the eye for a certain length of time to excite any impression, and such impression will continue even

4.) From *the number of things intervening between the eye of the observer and the object*, since by inductive reasoning from the distances of nearer objects we infer the distances of such as are more remote.

> If, when the distances are considerable, we have no intervening standard of measurement, our conclusions as to the remoteness of objects are often erroneous, and generally we are apt to underrate their distance: this has been experienced by most persons at some time when looking over a wide plane on which there were either few objects, or none at all, to serve as standards of measurement, especially when looking at a sea on which there were but few vessels.

5.) From *the position of the object relatively to some other objects whose distance is known;* in this case we use the known distance as a measure by which to judge of the unknown.

Our estimate of the distance of any object will be increasingly accurate, in proportion to the number of these elements which enter into our calculations. When objects are near to us, nearly all the points which we have been considering act together, and give greater certainty to our estimate. The greater the distance, the fewer of these auxiliaries there are to assist us, until certain limits are exceeded, when nothing remains on which to base our conclusions.

By the same means we determine the *relative positions* of objects to one another. We are principally guided by the angle of vision which the position of objects makes in our eye, *i. e.* by the space which intervenes on the retina between the images the objects produce. When this angle is of an average magnitude, our judgment will generally be most accurate.

We estimate the *motions* of objects by the movement of their images on the retina; to be perceptible, they must have a velocity which will cause the image to describe an arc of one minute in a second of time.

> Motions which produce a smaller change than that named above, in the angle of vision, are not appreciable by us; hence we do not see the hour-hand of a clock move, nor do we perceive the motions of the heavenly bodies.

## § 349.

Those colours are called *accidental* colours which are observe to be but transient on a body, or which continue to be depicte on the retina for a short time after the object which produced th impression has been removed; they are sometimes called *subjec tive* or *physiological* colours, to distinguish them from such as ar *permanent* to bodies, and which are termed *objective* colour hey are excited by the external impressions of light, under two istinct conditions, viz. when the eye has been very vividly affec-d by the action of white or coloured light upon it; and also by e contrast of a colour, when white light succeeds the coloured ays. The phenomenon, in the main, consists in this, that the rst vivid impression after some time induces its opposite in the ye; thus white light is succeeded by an *ocular spectrum* of black. nd each of the colours is followed by an image of its complenentary colour.

Instances of ocular spectra induced by intense luminous excitement:—

*First Expt.* Look steadfastly with both eyes upon a black figure (a wafer), on a white sheet of paper, on which the sun shines strongly; and then hold a handkerchief over your eyes, or turn towards a greyish or dimly illuminated wall; and you will have the impression of a white wafer on a grey ground. The converse obtains, if a white object be looked at, on a black surface.

A similar effect is produced, if a person look steadily for some time through a window, at white clouds; and then cover his eyes with a bandage, he will have a spectrum of dark clouds behind white window frames.

*Second Expt.* Lay any coloured object, as a red wafer, or, better still, a piece of red ribbon, on a sheet of paper, and look at it till the eye becomes weary with counting the threads; if the ribbon be removed quickly, a spectrum of green, the complementary colour to red, will be seen.

Dr. Böttger observed, that when a plate of white porcelain was substituted for the sheet of paper, in this and the preceding experiment, the accidental colours were rendered much brighter and purer.

*Third Expt.* Burn a small quantity of red fire in a dark room; extinguish it, and the eye will see a green flame. If the eye be closed, the green spectrum will be equally visible as if it be kept open. The succession of the colours will be inverted, by burning something that will produce a green light. A similar effect follows, if the setting sun be long and steadily looked at, its red disc being succeeded by a green spectrum.

That these colours are accidental, may be inferred from the fact that, if one eye be closed, whilst the other receives the impression from the light, the phenomenon takes place only in that eye, and not in the closed one.

*Fourth Expt.* If we look long at an object through a coloured glass, for instance, through a piece of violet glass, the object will seem to be illuminated by the sunshine.

*Experiments on ocular* spectra by contrast:—

*Fifth Expt. Coloured Shadows.* — Make two apertures, in the form of parallelograms, in a window shutter, the width of the holes being 4 to 6 inches, and their distance asunder, measured horizontally, from 1½ to 2 feet. Close one of the apertures with a stained glass plate, and the other with a wooden slide. Allow a coloured beam, through the first opening, to fall upon a rod, and it will project a black shadow on a white screen placed behind it; the rest of the screen being apparently of the same colour as the glass through which the light was admitted. In like manner, admit only white light through the other opening, and the rod will cast a black shadow on a white ground. Now, if light be admitted simultaneously through both the apertures, the rod will cast a shadow from each of the sources of light; but both of them will be coloured, instead of being black, as before; the shadow projected by the day-light being of the same colour with the stained glass, whilst the shadow cast by the coloured light, and partially illuminated by the sun's rays, exhibits the complementary colours. Thus, by means of a green plate, we get green and red shadows; by an orange plate, orange and blue shadows, &c. The size of the aperture by which day-light is admitted may be regulated by the wooden slides.

Coloured shadows may be obtained in a still more simple mode, thus: admit day-light through a small opening into a room, and project the shadow of any opaque object upon a white screen. Place a lighted candle or lamp at a proper distance from the body, and it will cast a second shadow; the former shadow becoming orange-coloured, and the latter blue. The shadow cast by the day-light is rendered orange by the orange rays of the artificial light; whence the shadow which it casts necessarily appears of the complementary colour.

*Sixth Expt. Spectrum of Complementary Colours by Doubl Reflection.* — Lay a plate of coloured glass on a commo looking-glass; if a small space, about a ¼ of an inch, be lef between the two surfaces, it will be better. Interpose between the plate and the looking-glass a sheet of black pape so that the under-surface of the stained glass may not refle the light; hold a sheet of white paper, on which a blac figure is marked, in front of the glass; and the drawing wi be reflected the same as in an ordinary looking-glass: th is to say, the white will appear white, and the black, blac If the black paper be removed, we shall have a double ima —one reflected from the surface of the coloured glass, a the other from that of the looking-glass. Take away black paper, the light will pass through the coloured gl which we will suppose to be green; the under-surface will accordingly reflect a green image; and the upper one, which before threw back a white image, will now reflect one of the complementary colour, red. If a yellow or blue glass be substituted for the green, corresponding results will follow.

The explanations hitherto given of these phenomena are as numerous as they are unsatisfactory. That of Petrini is the simplest and most natural. Every nerve, he says, becomes fatigued by an impression continuing long upon it; and every less powerful impression fades away, or is received less vividly, when accompanied by one more powerful. When, therefore, the eye has received a very powerful impression from any coloured light, the sensation of this colour disappears from the more feeble white light, and the complementary impression alone remains. In short, if the eye is affected by any predominant colour, it immediately receives the sensation of its complementary colour, just as when a string is struck, the ear perceives simultaneously the fundamental note and the note that harmonizes with it.

## XI. THE PRINCIPAL OPTICAL INSTRUMENTS.

### 1). *The Camera Obscura.*

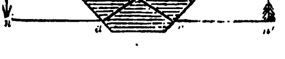
### § 350.

The *Camera Obscura*, as its name imports, is a dark chamber, enclosed on all sides: as generally constructed, it is a box, painted black inside; the light from external objects being admitted into it through a convex lens, which, collecting the rays transmitted through it, forms an inverted image of these external objects (§ 314.) at the focus where the refracted rays meet: the image thus produced is received on a white screen.

To obtain an erect vertical image, according to Horner, we should use a right-angled prism, which will refract a second time, and in an inverted position, the rays transmitted through the convex lens.

Let A B C, *fig.* 93., represent the prism, and *m a*, *n d* two rays which have passed through the convex lens and produce the inverted image *m n*; then, as the diagram shows, *m a* is refracted in the direction *a b c m'*, and *n d* in the direction *d f g n'*; whence it follows that *m' n'* must be an inverted image of *m n*.

*Fig.* 93.



If we wish to obtain the image on a horizontal plane, should make use of a plane mirror, inclined at an angle of 45 the axis of the lens; by which means the rays, after pas through the lens, will be reflected either upwards or downwa In the first case, the image is generally received on a plat ground glass, through which it shines so as to be visible fr above. This apparatus is sometimes called a *camera clara*. the second case, a sheet of white paper is usually placed receive the image horizontally, the mirror being made to ref the rays downwards, instead of upwards; the spectator must this arrangement, either be himself within the camera, or must look in upon the images through a small round hole, m for this purpose, in the side of the instrument.

The images formed by the camera obscura depict most ac rately the forms, colours, and degree of illumination belong to the different objects; it has the additional charm of presentin with an animated picture, the movements of external objects be repeated in the image. It represents, on an enlarged scale, w is continually taking place on the retina of our eyes.

> Why are not the images of near and distant objects p sented to us with equal distinctness by the camera? — H can we adjust the instrument for distinctly representing jects at different distances? — If the image formed by convex lens is received on a convave instead of on a pl surface, the whole picture will be rendered distinct. Wh — Advantages derived from the use of an achromatic con glass. — Why is a metallic speculum preferable to the co mon looking-glass, generally used in this instrument?
>
> The camera obscura was invented in the 16th centu by John Bap. Porta. Wollaston's camera lucida is n more generally used than the former instrument, to obt mechanically correct representations of natural objects.

### 2.) *The Different Kinds of Microscopes.*

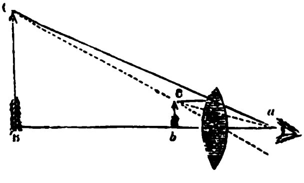
### § 351.

The use of a microscope is to furnish us with magnified im of objects so minute, that when held at the distance of dist vision, the eye would be incapable of distinguishing their f and parts. This is accomplished by enlarging the optic an for every object appears greater according as we increase gle; greater, consequently, as we bring it nearer to our eye § 348.): but we cannot bring an object nearer than the distance of distinct vision, *i. e.* within from 8 to 10 inches of the ye; for if we do, the angle of vision and the image of the object ecome so enlarged, that the image is projected beyond the retina, nd is of necessity indistinct.

> *Expt.* Prick a card with a fine needle, and placing yourself before a window, look through the puncture at a needle, which must be held at the distance of distinct vision, and in a line with your eye: you will observe that the image of the needle is considerably magnified the nearer it is brought to the aperture in the card, till, when it is close to it, the outline of its eye becomes altogether indistinct.

The *single microscope* consists of a convex lens, with a very short focal distance. If an object be viewed through it at less than its focal distance, but near to the focus, the rays transmitted through the lens will be rendered more convergent, and an eye on which they fall will see the object under a greater angle of vision, *i. e.* it will see the object magnified.

*Fig.* 94.



An eye *a*, *fig.* 94., would see the object *b c* under the angle *b a c*: interpose between the eye and the object a convex lens *m*, at the proper distance, and the rays will be refracted (§ 311.), as shown in the *fig.*, so that the object will be viewed under the larger visual angle B *a* C; the object itself will, therefore, appear magnified as B C.

The image of an object produced thus will be thrown back by the eye to the distance of distinct vision, viz. to 8 or 10 inches from it. A short-sighted eye would require that the object should be brought nearer to the glass, and a far-sighted person would place the object further from him; it would, therefore, appear more highly magnified to the latter than to the former. The linear magnifying power of such a lens will be nearly the multiple that the distance of distinct vision is of its focal length.

We have said above, that the distance *b m*, *fig.* 94., at which the object *b c* is to be placed before the lens, must be nearly equal to its focal length in order to obtain from it the greatest possible magnifying power; let B *m* be the dis-

[illegible] image magnified again by the eye-glass C, and se [illegible] A under the angle of vision $a^2$ A $b^2$.

If we suppose the magnifying power of the object-glass to be 20, so that c d = 20 a b, and that of the object-glass 5, so that $a^2 b^2$ = 5 c d, $a^2 b^2$ = 20 × 5 = 100 a b; or, in other words, the eye will view the object under an angle 100 times larger than it would have done unaided by this instrument. — The [illegible] magnifying power is found in the same manner as that of single microscopes.

Dr. [illegible] gives the following method of testing pretty nearly the magnifying power of one of these microscopes. Place some object of known size before the object-glass, look with one eye through the microscope, and with the other at the point of a pair of compasses which you hold at the distance of distinct vision before the other eye. Open the legs of the compass to such a distance as equals the diameter of the object viewed through the microscope. Divide this diameter by the actual diameter of the object, both being in the same denomination, and the quotient will give the magnifying power required.

Advantages derived from the use of achromatic object-glasses. — Microscope with more than two convex lenses. Campani's collective lens.

## § 353.

The solar *microscope* is nothing more than a magic lantern, the light of the sun being used instead of that of a lamp. The object to be magnified is strongly illuminated, and its inverted image formed by a convex lens of short focal length, is projected on a screen: the object is to be placed near but a little beyond the focus. The rays of light which pass through the object are so refracted by it (§ 311. 5.) that they form an inverted image at a certain distance from it; which distance and image [illegible] the nearer the object is to the focus. The linear magnifying power is proportional to the distance of the image [illegible] divided by its focal length, or it equals the diameter [illegible] divided by that of the object. If the light be sufficiently [illegible] a more brilliant image will be obtained than from [illegible]

Instead of the light of the sun, or of a lamp, there has been [illegible] light generated by the combustion of a [illegible] stream of oxy-hydrogen gas, whence the [illegible] *hydrogen microscope*. The intensity [illegible] cylinder of the ignited lime half a [illegible] light greater than that yielded by 15 [illegible] the object sufficiently, a conve s is used of considerable size to refract the rays of the sun, mp, or ignited lime, so that they may fall together on the object. his lens is called a *collective* or *illuminating lens*.

### 3.) *The Different Kinds of Telescopes.*

### § 354.

Telescopes are used for much the same purpose as microscopes, iz. to present objects to our eye under a greater visual angle, nd consequently with their proportions enlarged. The difference n the application of the two classes of instruments is, that elescopes serve to magnify objects that appear small from their great distance, whilst microscopes are used to magnify minute objects near us.

Telescopes are either *refracting* telescopes, and consist entirely of lenses combined together, or of lenses and concave specula when they are said to be *reflecting* telescopes.

Telescopes, like microscopes, magnify objects by enlarging the angle under which they are viewed. Their power equals the quotient of the visual angle of the eye looking through a telescope divided by the visual angle of the naked eye.

The space or range seen through a telescope is technically termed the *field of vision*. It is measured by dividing the angle under which it is seen by the angle of vision of the naked eye embracing the same field within its view: the greater the magnifying power of the instrument, the less will the angle of vision of the naked eye be compared with that of an eye looking through the glass.

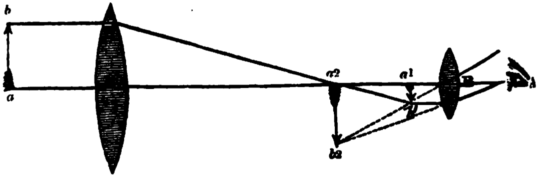
It is requisite that the objects viewed through a telescope should be seen with the greatest possible *distinctness*, and that they should appear as strongly *illuminated* as possible. Now, the combination of these two essential properties is not very easy; for, to admit a large quantity of light into the tube we must enlarge the dimensions of the lenses, whereas to obtain distinct images it is needful to use lenses of the smallest available size. The object aimed at in the construction of telescopes is therefore to secure the greatest attainable distinctness of the image consistent with the admission of an adequate degree of light.

### § 355.

Refracting telescopes are of three kinds, viz. Keppler's, or the *astronomical telescope*, invented by Keppler, 1611; the *terrestrial*, invented by the Jesuit Maria de Rheita, about the year 1630; and the *Dutch* telescope, or Galileo's telescope, first made by Jansen in 1590. The two first are merely combinations of convex lenses, the last consists of both convex and concave lenses.

The *astronomical* telescope is made by placing two conv lenses of unequal focal lengths one before the other, in such manner that they may have a common axis. The farther lens termed the *object-glass;* it forms an inverted image of the objec seen through it; if they be very distant the image will be near the focus of the glass, and in proportion as their distance diminishes the image recedes from the focus. (§ 311. 1, 2, and 3.) The observer views this image through the second or *eye-glass*, in the same manner as through a single microscope: the image will therefore be seen by him under a greater optic angle, and consequently it will be magnified, but will still be inverted. — From this explanation the similarity in construction and in principle of these telescopes and of compound microscopes is evident. — The lenses are generally distant from each other a space equal to the sum of their focal lengths; but if less distant objects are viewed through the instrument, the lenses must be adjusted for a wider distance, that the image formed by the object-glass may fall beyond its focal length. — The magnifying power is found by dividing the focal length of the object-glass by that of the eye-glass.

*Fig.* 96.



Let *Fig.* 96. be a representation of the astronomic telescope: *a b* is the object viewed, which must be suppos to be at a considerable distance; C is the object-glass behi which and a little beyond whose focus will be the sam inverted image *a' b'*; B is the eye-glass which magnifi this image, so that it is seen by an eye at A, as represent at $a^2 b^2$.

Suppose the object-glass to have a 10 inch focal lengt and that the eye-glass has only 1 inch, then the instrume magnifies an object seen through it 10 times; if t object-glass have a 100 inch focal length, the same eye-gl would magnify an object 100 times; if we substitute eye-glass with a focal length of ½ an inch, then the magnif ing power would be 200 times.

As its appellation indeed shows, this instrument is used pri cipally in making astronomical observations; for which purpose t inversion of the images is of small consequence. Its advantages are, that with an entensive field of vision it admits a large quantity of light, and possesses higher magnifying power than the other telescopes.

The *night-glass* resembles the astronomical telescope; it differs from it in this, that it has an object-glass of wider aperture and shorter focal length; by which arrangement its magnifying power is less than that of the astronomical telescope, but it presents a wider field of view, admits more light, and consequently shows objects more distinctly. It is serviceable in bringing a larger portion of the heavens under observation by night, and in detecting such heavenly bodies as have but feeble illuminating powers.

The *terrestrial telescope* consists of at least four convex lenses; it may therefore be regarded as a double astronomical telescope, all the glasses having a common axis. The inverted image formed by the object-glass of the anterior astronomical telescope is again inverted and magnified by the posterior telescope, and is therefore presented erect to the eye of the observer. As these instruments present objects in their natural position, they are used chiefly for viewing distant objects on the surface of the earth; and hence their name. Like the astronomical telescope they have a large field of sight; but in consequence of the repeated refraction of the light it becomes much diminished, so that objects cannot be as much magnified in them, as in the astronomical telescope, without the distinctness of the image being impaired.

The terrestrial telescope is represented in *fig.* 97. L is the double convex object-glass, of great focal length; $o^1$, $o^2$, $o^3$ are three double convex eye-glasses, of shorter but equal focal distances, set in one tube, so that the posterior focus of one eye-glass may coincide with the anterior focus of the next. These foci are marked on the axis *a* A. For use, the instrument must be so adjusted that the object-glass L shall project the inverted image *a′ b′*, which it forms a little beyond the anterior focus of the first eye-glass. If an observer were to look through this glass, he would perceive

*Fig.* 97.

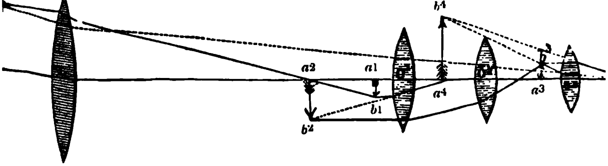
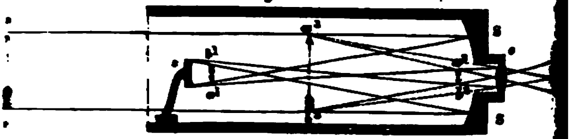


Fig. 101.



erect image $a^2 b^2$, which, to an eye at A, will be magnified in $a^3 b^3$. This form of telescope is superior to the other two, in much as, in making observations, it can be directed towards th object in the direction of the line of sight; and next, that obje viewed in it are presented in an erect position. The disadvanta connected with it are, that the quantity of light is diminish and the objects are seen less distinctly, in consequence of th aperture made in the middle of the object speculum.

As the owners of telescopes may perhaps wish to be abl to estimate their magnifying power, and the extent of thei field of vision, it may be worth while to give the followi method as described by Dr. August: —

The *magnifying powers* may be estimated pretty n by looking at the same object with one eye through th telescope and with the other naked, and comparing the apparent magnitudes of the two images. This measurement may be rendered still more exact if any kind of telescope, except a Galilean, be pointed towards a clear part of the sky, and a leaf of thin paper or transparent horn be held behind the last eye-glass, at the spot where the eye is ordinarily placed; a bright, strongly-defined luminous circle will be visible on the transparent plate, supposing it to be held at the right spot. Measure its diameter as accurately as possible, and then measure the width of the object-glass, using the same scale in each case, divide its diameter by that of the luminous spot, and the quotient will give the magnifying power of the telescope.

The luminous circle is, in fact, an image of the object-glass itself, whence it may be proved that it is contained in the diameter of the object-glass as many times as are equal to the magnifying power of the telescope. The object-glass may be taken out, and a rim, or annulus, having exactly the same opening as will be equal to the circle of light, put in its place; the quantity of light will be increased, and the images of objects rendered more distinct by this alteration. — Ramsden contrived a little instrument, to which he gave the name of *Dynamometer*, for measuring the powers of telescopes.

The *field* of a telescope may be estimated by comparing its diameter with the apparent diameter of some object viewed through the telescope. In the choice of an object, one should be selected whose apparent diameter is already known to us; that of the sun or moon will answer the purpose well; they are both equal, or very nearly so, the apparent difference amounting only to half a degree, or 30 minutes. — Or, the field may be measured by directing the telescope to some star in or very near to the equator, care being taken that it shall pass over the *middle* of the field, and then count the number of seconds which elapse during its passage: four seconds of time will make an angle of one minute for the field of vision.

### I. THE THERMAL, CHEMICAL, AND OTHER NON-OPTICAL EFFECTS OF LIGHT.

### § 358.

All the phenomena of light which we have hitherto noticed are of a purely optical nature, *i. e.* they are such as act only on our organs of vision. Light, however, is an active agent in bringing about quite another class of phenomena; it excites *heat* and *electricity*; on most bodies it exerts a *chemical* influence, and displays a vivifying power in its operations on organic matter; whether it possesses *magnetic* properties is a matter of doubt.

As to the excitation of heat, it has not yet been proved that this property is possessed by all sources of light, though it is known that the sun's rays have it in a high degree: it appears to stand in a direct ratio to the intensity of the illumination and the absorptive power of the body. The heating powers of the differently coloured solar rays are extremely unequal, the greatest heat being found to exist near to, but slightly beyond, the red rays in the solar spectrum, their respective heating powers decreasing till we arrive at the violet, where this property ceases altogether. A more detailed explanation will be found in the CHAPTER ON HEAT.

The *chemical properties* of light are shown in this, that the light of the sun, and, in an inferior degree, that of day when the sun is hid from our view, is a means of accelerating chemical combinations and decompositions. Thus, as we have already mentioned, the rays of light seem to carry with them both thermal and chemical rays; the maximum intensity of the former spectrum coinciding with the red rays, whilst the maximum of the chemical spectrum is found in the violet light and a little beyond, its intensity diminishing gradually throughout the other colours till its effects entirely cease at the red.

Its effects are not less important when produced in ina
matter, for it is heat which brings about *changes* in the
and in the *aggregate form* of bodies; by it also many subs
are rendered luminous; by it their electrical and magnetic
dition is influenced; and, lastly, by it the chemical acti
bodies on one another is greatly affected.

In consequence of the influence which heat exerts
organic life, man himself may be regarded as, to a c
degree its slave; viewed from another point, he is the m
of this powerful agent, controlling and directing its
tions on other bodies at his bidding. The use made b
of this power, in supplying his natural and artificial w
is so varied and important, that if deprived of these reso
he would become as helpless as the beasts of the field. T
considerations may well incite a desire to become b
acquainted with the nature of this important agent,
with its mode of operation.

## § 360.

Heat, like gravity, is a universal force; it moves accordi
its own peculiar laws, and when certain conditions are fulfi
it is in a state of equilibrium. Heat is said to be *free*, or *sen*
when it displays a tendency to establish equilibrium, by equ
diffusing itself in all surrounding bodies; hence it is in ince
motion, passing from one to another. The quantity of it pr
at any moment in a particular body is said to be the *temper*
of that body. When its movement ceases, and it is in a tempo
state of repose, intimately uniting itself with the atoms of m
and not causing any change of aggregation, nor apparently t
ing to do so, we then say that it is *latent*.

## § 361.

By the term *heat* we sometimes mean both the cause an
effect; the former, however, is more accurately expressed b
word *caloric*, heat serving to mark the science which trea
the properties, effects, and laws of caloric.

*Heat* expresses an increase, as *cold* does a diminution i
sensation of warmth; heat and cold are therefore positive
negative magnitudes, resembling in this respect light and d
ness. Both sensations are merely relative, the feeling of
arising when more caloric is received by our bodies th
required in a normal state of vitality. The feeling of co
excited when a portion of the requisite warmth is abstra
*Probably*, these opposite sensations are merely the results

nge in the volume of our organs; that is to say, *heat* is the sation caused by the *expansion*, and *cold* the *sensation* caused the *contraction* of the parts of our bodies.

## § 362.

We are as imperfectly informed as to the nature of heat, as we re with regard to the nature of light. We know that it exists nly by its effects: but to explain these, we are obliged to have ecourse to theory. The principal hypotheses will be briefly oticed here; but at the conclusion of this section, they will be reated of at greater length.

According to the more ancient theory, it was regarded as an imponderable material substance, which, being combined with bodies, under various modifications, produced all the phenomena of heat. Other philosophers considered heat to be merely modified light, assuming that an identity subsisted between the two. The opinion most generally received, in modern times, is that the phenomena of heat, like those of light, are best explained, by attributing them to the undulations of an æther, whose existence we assume, the velocity with which the fluid moves being less when it produces heat than when it generates light.

## II. CHANGE IN THE VOLUME OF BODIES CAUSED BY HEAT.

## § 363.

Experience teaches us that *heat increases the volume* of a body. When the sensible caloric in a body is increased, or its temperature is raised, then the body dilates; but when the temperature is lowered, its volume is diminished. Both these effects admit of being measured; the dilatation and contraction are equal in all directions, a small number of crystals only excepted.

This effect of heat has been explained on the supposition that the increase of caloric between the atoms of any body causes them to recede, and that the decrease of the caloric allows them to approach other. According to La Place, heat is itself the repulsive force that, residing in the atoms of which a body consists, drives them asunder when it becomes increased; and when this force is diminished, the power of attraction draws them together. According to Ampère's theory, the changes in a body's volume are owing to the different intensity of the oscillations performed by the æther, which he supposes to exist between the atoms composing it.

stances, on account of the irresistible force with which they expand and contract; and this force must be noticed especially, when several different substances are combined in one piece of mechanism. (5)

## TABLE X.

*Of the Longitudinal Expansion of different Solid Bodies caused by raising them from a Temperature of 32° to one of 212° Fahr.*

| Substances. | Length at 212°, length at 32° being = 1. | Index of the Expansion, at 212°. | By whom observed. |
|---|---|---|---|
| Earthenware, brown English - | 1·00012000 | $\frac{1}{8333}$ | Destigny. |
| Fir - - - | 1·00035200 | $\frac{1}{2841}$ | Struve. |
| Glass, a mean - | 1·00089694 | $\frac{1}{1116}$ | Lavoisier and Laplace. |
| Platinum - - | 1·00098390 | $\frac{1}{1016}$ | Dulong and Petit. |
| Steel, soft - - | 1·00107956 | $\frac{1}{926}$ | Lavoisier. |
| Cast Iron - - | 1·00110940 | $\frac{1}{901}$ | Roy. |
| Bar Iron - - | 1·00115600 | $\frac{1}{865}$ | Borda and Tralles. |
| Ditto - - | 1·00126660 | $\frac{1}{790}$ | Dulong and Petit. |
| Steel, hardened - | 1·00136900 | $\frac{1}{730}$ | Lavoisier. |
| Gold - - - | 1·00146606 | $\frac{1}{682}$ | ——— |
| Bronze - - | 1·00181667 | $\frac{1}{550}$ | Smeaton. |
| Copper, hammered | 1·00184110 | $\frac{1}{543}$ | Dulong and Petit. |
| Brass, cast - - | 1·00186671 | $\frac{1}{535}$ | Lavoisier. |
| Brass Wire - | 1·00187821 | $\frac{1}{532}$ | ——— |
| Silver - - | 1·00190974 | $\frac{1}{524}$ | ——— |
| Tin - - - | 1·00217298 | $\frac{1}{460}$ | ——— |
| Lead - - - | 1·00284836 | $\frac{1}{351}$ | ——— |
| Zinc, cast - - | 1·00294167 | $\frac{1}{340}$ | Smeaton. |
| Zinc, hammered - | 1·00310833 | $\frac{1}{322}$ | ——— |

A standard measure gives the required length correctly, only at one particular temperature. If the temperature exceed this normal temperature the dimensions of the rod will be too great; if it be less, then the dimensions will be too small; and this variation depends, not merely on the degree of heat to which the standard is subjected, but also to the material of which it is made. Standards of wood or glass vary but little at ordinary temperatures; hence the utility of employing thermometer scales of one or other of these substances in preference to those made of metal. In a metal scale one foot in length, corrections for temperature are indispensable to secure accurate results. Let $l$ be the length at temperature $t$, and $\lambda$ the correct length of the standard at the normal temperature $\tau$; and let $1 + m$ be the coefficient of the expansion of its material at the boiling point of water; then, from the formula

$$l = \left[1 + \frac{m\,(t-\tau)}{100}\right],$$

we shall obtain the true length, $\lambda$, for the centigrade scale, with sufficient exactness,

$$\lambda = l\left[1 - \frac{m\,(t-\tau)}{100}\right];$$

and for Fahrenheit's scale

$$\lambda = l\left[1 - \frac{m\,(t-\tau)}{180}\right].$$

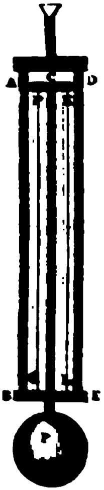
Hence we see why, in accurate barometric measurements, we are obliged to make a correction for the scale of the barometer, according to the temperature at the time of making the observation.

So, also, it is easily perceived why the moulds for all sorts of cast-iron work should be rather larger than the article itself is wished to be.

2.) If a pendulum is intended to serve as an exact measurer of time, we must contrive that its length shall be altered as little as possible through variations in temperature. (§ 108. 1.) Consequently, it is advisable to select for the rod of the pendulum some substance that is but slightly affected by heat, and to place the instrument in such a situation, that it may be subjected to as little change as possible; deal, well seasoned and then soaked in oil and baked, will be found a very good material. The best pendulums, called *compensation pendulums*, are made of different substances, so combined that the effects of heat counteract each other, and the length of the rod remains unaltered.

The commonest compensation pendulum is *Harrison's gridiron pendulum*. It is represented in its most simple form, *fig.* 106. The proper rod C P is of iron; so, also,

*Fig.* 106.



are the bars A B and D E; but ones, F G and K L, are of zinc. both these metals will be affected neously by a change of temperatur when the iron expands P is made to but a corresponding expansion of elevates it; it follows that P, being by two equal antagonist forces, nei nor falls. Since the expansion of zi that of iron, the bars must not be eq such a relation must be established them, that the elevation or depressi bob by the one metal may be exac teracted by the depression or elevati other, with every rise or fall of tem This is accomplished by making th of the two metals inversely as thei sions. The lengths of these rods

determined by the formula, $l =$

$l$ being the length of the zinc bar, L the iron, $i$ the expansion of the iro that of the zinc. Now, as the exp

iron is to that of zinc (Table X.), a

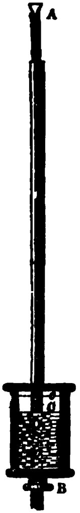
$\frac{1}{340}$, or as 1 : 2·324; for these two m

formula becomes

$$l = L\frac{1}{2{\cdot}324-1} = 0{\cdot}755\,L.$$

One of the most simple, and at the same time in contrivances, was that of *Graham* (1721), who con the *mercurial compensation pendulum*. This instrume sists of an iron rod A B (*fig.* 107.), to the lower extr which a branch is fitted to embrace a cylindric gla B C, containing quicksilver. The theory of this pe is extremely simple. As the point O of the pen oscillation is about the middle of the vessel of merc it is clear that an increase in the temperature will l the rod A B, about O o, so as to depress the c oscillation to $o$; but the simultaneous expansion mercury elevates this point to O. This result is attained when the expansion of the mercurial C B is just double that of the rod A B, *i. e.* w space C c, through which the quicksilver rises in th is equal to twice O o. Now, suppose the distance int of suspension from the centre of oscillation, or the length of the second's pendulum to be 39·13929 inches = 479·67 lines, then A O = 479·67 lines. B O is half the height of the quicksilver in the vessel, and A B the entire length of the metal rod. Now, let $i$ denote the expansion of the iron, and $q$ that of the quicksilver, then A B would expand $AB \, . \, i$, and O B would expand $OB \, . \, q$. In order that these two expansions should counteract each other, it would be necessary that $AB \, . \, i = OB \, . \, q$. But $AB = 39{\cdot}139 + OB$, whence the equation becomes

ig. 107.



$$i\,(39{\cdot}139 + OB) = q \, . \, OB\,;$$

$$\therefore OB = \frac{i \, . \, 39{\cdot}139}{q - i}.$$

The expansion of iron between the freezing and the boiling points of water, according to Dulong and Petit (see Table X.), is 0·00126, and the expansion of mercury between the same temperatures, according to the same philosophers, is 0·01801, but as Horner says, 0·0175 if the expansion of the glass also be taken into account, thus,

$$i : q = 126 : 1750,$$

or nearly $\qquad = 1 : 14.$

and $OB = \dfrac{39{\cdot}139}{14 - 1} = 3{\cdot}01$ inches.

The entire length of the mercurial cylinder B C will, therefore, be 6·02 inches.

Both the mercurial and the gridiron pendulums will require regulating, the former is corrected by pouring in or taking out of the cup very small portions of mercury, the latter, by turning a screw up or down, so as to raise or depress the point of oscillation.

The compensation in a chronometer depends on the same principle, different metals being so combined as to render the oscillations isochronous.

3.) In tubes for conveying water, steam, or gas, it is necessary to make provision for the expansion and contraction of the metal. Similar adjustments have to be made in machinery into which large pieces of iron-work enter. Room is left to allow for the change of volume in boilers and similar *vessels.*

The following simple experiment will illustrate the of the last remark: —

Expt. Plunge the bulb of a thermometer into hot w at first the ascent of the mercury in the tube will be rapid; but the nearer the temperatue of the metal app mates to that of the water, the smaller its expansion.

Experience proves that heat is capable of being dif throughout all substances, without exception, and that no ma exists which can exclude it.

## § 391.

It has been found, by numerous experiments, that *the cond of heat in the interior* of bodies, both solid, liquid, and gaseo regulated by the same law; but that equal volumes require unequal times, according to the conducting power of the parti substance; and that, generally speaking, the denser any bo the better conductor of heat does it become. This equaliz of temperature is considerably modified in liquids and gase the extreme mobility of their particles.

In solid bodies heat extends itself from the particle in im diate contact with the source of heat to the next particle; fr again to the next, and so on, until the whole mass has acq the same temperature. The best conductors of this class of stances are the metals, but among them there exists a great d sity in this respect. Metals in an oxidized state, as they found in most stones, glass, burnt clay, &c., have a mean ducting power. Organic bodies are bad conductors of h as instances, we may mention cork, straw, charcoal, ashes, co wool, silk, hair, feathers, &c.

Rumford considered that these porous bodies were conductors of heat, in consequence of the portion of air quiescent state contained in their interstices. Heat tr more slowly, in proportion as it passes frequently out o substance into another, of different densities.

Despretz has represented the conducting powers of va bodies by the following numbers: —

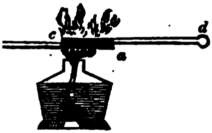
| | | | |
|---|---|---|---|
| Gold | 10,000 | Tin | |
| Silver | 9,730 | Lead | |
| Copper | 8,980 | Marble | |
| Platina | 3,810 | Porcelain | |
| Iron | 3,743 | Tile | |
| Zinc | 3,630 | | |

Woods are among the substances that have the lowes ducting power. De La Rive arranges them in the foll der: nut, oak, fir, poplar, cork. He considers, also, that ey all conduct heat better in the direction of their fibres an across the grain.

The following simple experiment will at once show the feriority of glass to metal as a conductor of heat: —

*Expt.* Let *a b*, *fig.* 109., be a piece of brass, copper, or iron wire; and *c d* a piece of glass of equal size and length. Tie both the rods firmly together at one end by a bit of wire, and put a ball of wax at their other extremities. Heat the apparatus by applying to it the flame of a spirit lamp; and the wax at *b* will be completely melted, whilst that at *d* is unchanged.

*Fig.* 109.



## § 392.

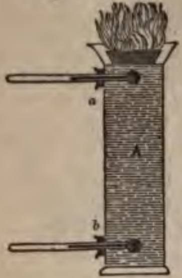
propagation of heat in non-elastic fluids varies according as plied from above or from below. If heat be applied at the surface, the conduction proceeds just as in solid bodies, and case liquids prove themselves very bad conductors of heat; eated from beneath, their particles rise successively to the surface, their elevated temperature rendering them specifighter than the cooler particles above them; the greater of which causes them to descend and take the place origiccupied by the others. Thus, a constant current is excited liquid heated from beneath, by which the conduction of roughout its mass is greatly accelerated. The process is reversed if a fluid be cooled from above or from beneath.

The following experiments may serve to confirm the truth the above remarks: —

*First Expt.* Partly fill a tall glass vessel with water, and row in a little roughly-powdered amber; heat the water a spirit lamp, and the current in the fluid will be renred visible by the ascent of the particles of amber up the ddle of the fluid, but on their approach towards the sides the vessel, they will sink again with the cooler particles of water.

*Second Expt.* Let A, *fig.* 110., be a vessel made of plates iron or tin; near the bottom of one of its sides insert a ermometer *b*, and also a second thermometer at *a*, near the of the vessel. Fill it with water just above *a*; *c* is a n metal cup floating on the surface of the water, which is be filled with *spirit of wine* or sulphuric æther; light the spirit, or, if you please, fill the cup with as much hot sand as it can carry, and the heat produced by it at the surface of the water will very soon be shown by the thermometer *a*: the thermometer at *b* will meanwhile be scarcely affected by it.

*Fig.* 110.



Place the vessel on a lump of ice, and the lower thermometer will in a little time mark a change of temperature, but the thermometer *a* will not indicate any alteration till long after.

*In both these cases water is shown to be a bad conductor of heat.*

When the temperature of the water at the lower part of the vessel has fallen to about 39° Fahr., the water rendered lighter thereby begins to ascend (§ 376. obs.), and the warmer water above to descend and take its place.

Now place the vessel on a hot brick, and conduction will take place from the bottom, the elevation of the temperature will speedily be observable in both the thermometers. The water beneath being heated is rendered lighter, and rising rapidly, it acts on the upper thermometer.

Lay a piece of ice on the surface of the water, and both the upper and lower thermometers will quickly indicate a decrease in the temperature. The water on the surface, as it cools, becomes also heavier, and as it descends it affects the lower thermometer.

In the torrid and temperate zones the temperature of the sea will diminish as the depth below the surface increases, but in the frigid zones the reverse will happen, for as the temperature at the surface is less than 32°, the lower strata cannot have a less degree of warmth than 39°. Hence the formation of ice always begins at the surface; were the change of form in water to begin at the bottom, the whole mass would be converted into ice.

Aeriform bodies closely resemble the non-elastic fluids in the conduction of heat, these two classes of bodies being distinguished by the readiness with which their particles move among each other, and both having the same conditions of equilibrium. Air, in a tranquil condition, is a very bad conductor of heat, but when agitated, it promotes the propagation of heat, more quickly even than liquids, by the more rapid ascent of its heated particles.

To this property of air we must attribute the motions in our atmosphere, noticed already in the observation to § 206

*By referring* to the unequal power various bodies possess fo *conducting* heat, we can explain many circumstances that com der our notice in our ordinary experience. Thus, *to commu-cate heat quickly* we must make use of such substances as are od *conductors*; if we desire, on the contrary, *to retard* its ope-tions, we must select such bodies as are *bad conductors.*

From what has been already stated, the student will be able at once to answer the following queries, and to explain the technical uses of the various conducting substances.

Why do brass cannon become hot more readily than iron? If we touch a piece of wood and a piece of metal both at the same temperature, the latter feels colder than the former, if the temperature be lower than that of our own body; but if the temperature of these substances be higher than that of our bodies, then the metal feels hotter than the wood. Water is made to boil sooner in metal vessels than in earthenware. Wooden walls and thatched roofs are cooler in summer and warmer in winter than brick walls and tiled roofs. Wool, feathers, and fur are a better protection against inclement weather than several wraps of linen or leather. Snow is one of the worst conductors of heat. Utility of this property.—If our bodies come in contact with water and quicksilver, the sensations they excite are precisely similar to those caused by touching wood and metal. Use of making boilers, saucepans, and similar vessels, with wide bottoms. Use of double windows.

## IV. CAPACITY FOR HEAT.—SPECIFIC AND RELATIVE HEAT OF BODIES.

### § 393.

Similar bodies require *an equal quantity of heat* to raise them from any given temperature to a higher.

*First. Expt.* This may easily be proved by placing two equal cups of like material on the hob of a stove in which there is a fire; let each of the cups contain an equal quantity of water of the same temperature; each cup, therefore, contains the same quantity of heat. After a time the water will be found to have become hotter, but the temperature of that in each of the vessels will still continue equal.

If we assume the quantity of caloric requisite to raise 1lb. of water 1° above the freezing point for our unit of measurement, then we should require 20 times as much to raise 1lb. of water from 32° to 52°, or 120 times as much to raise 6lbs. the same number of degrees.

If similar substances of unequal magnitude or masses have the same temperature, *the quantity of free caloric they contain will be proportional to their masses.* If, on the contrary, they have different temperatures, and they are brought into contact, or a mixed together, then the free caloric is equally distribut throughout the whole mass.

*Second Expt.* Mix together 1lb. of water at 52° and 1lb at 72°, and you will obtain 2lbs. at $\frac{52+72}{2} = 62°$.

If their masses are unequal, their common temperature, after combination is found by dividing the sum of the products of their masses into their temperatures by the sum of their masses, thus, *ex. gr.* mix 2lbs. of water at 95° with 3lbs. at 50°, and the compound will have a temperature of $\frac{(2 \times 95) + (3 \times 50)}{2 \times 3} = 68°$. — Practically, some portion of the heat will be absorbed by the vessel.

If you put M and $m$ for the masses, T and $t$ for the temperatures of the bodies, and $x$ their common temperature after contact or mixture, the general expression will be

$$x = \frac{M\,T + m\,t}{M + m}.$$

## § 394.

If the temperatures of two dissimilar substances be raised to the same degree, experience proves that some substances require more and others less heat.

*Expt.* Place side by side upon a hot plate two equal similar vessels, one containing a certain quantity by weight of water, and the other an equal weight of mercury, If both the fluids stand at the same temperature, it is clear, under the circumstances supposed, that each vessel contains an equal quantity of caloric; after a very short time, however, we shall find that the mercury has become much hotter than the water.

In like manner, it has been found in lowering the temperature of dissimilar substances to an equal degree, that some give out more and others less caloric.

Hence it follows, in most cases, that if two dissimilar substances whose masses or weights are equal have the same temperature, they contain unequal quantities of heat.

We attribute, therefore, to bodies a different degree of susceptibility for receiving free caloric into their interior structure, or within their molecules; this is called their *capacity for heat*, and the quantity required to raise equal masses or equal weights, is termed their *specific heat*. It has also been determined, that a *certain relation* subsists between the density of bodies and the

city for heat, this capacity in general being less, the denser
structure of the substance.

we determine the specific heat of different substances, we
compare their respective capacities for heat. To do this in-
gibly with regard to all bodies whatever, we must proceed in
h the same manner as we did to ascertain their specific gra-
s. (§ 173.) The unit assumed for this purpose is the capa-
of a certain weight of pure water. Equal masses of other
stances are compared with this unit thus: if their capacity for
t exceed that of water, by numbers greater than 1; if it be
than that of water, by fractional quantities.

The specific heat of bodies has been determined, not only for
al weights, but also for equal volumes, and this is called their
*tive heat*, which is to the specific heat of any body directly as
specific gravity. It may be found by multiplying the specific
t into the specific gravity; and conversely, the specific heat
y be found by dividing the relative heat by the specific gravity.

It has been found by experiments, which will be detailed in the next section, that the quantity of heat requisite to raise the temperature of 1lb. of water 1°, would suffice to raise 1lb. of quicksilver 33°. If, then, we assume the quantity required for water as unity, the specific heat of mercury will be $\frac{1}{33}$; and since (Tab. IX. p. 187. Vol. IV.) the specific gravity of mercury is about 13·6, it follows that the relative heat of an equal volume of this metal is $\frac{1}{33} \times 13\cdot6 = 0\ 4121$.

Let $s$ represent the specific gravity, $c$ the specific heat or the capacity of the body for heat, then $r = sc$ will be the general expression for the relative heat of bodies, or the quantities of heat they contain with equal volume. The following table exhibits at one view the specific and relative heat of some of the principal solids and liquids.

With regard to gaseous bodies it has been found, that, whether
gle or mixed, their specific heat is inversely as their specific
vity or density, and, consequently, equal weights of such
ses contain a larger quantity of heat the less their specific gra-
y. But further, as the relative weights of equal volumes of
are inversely as their specific gravities, it follows that equal
umes of these gases will have equal relative heat; *i. e.* they
l contain equal quantities of caloric, in fact, the same as atmo-
eric air itself. Chemically combined gases, on the contrary,
e a different relative heat from such as are simple or merely
ed; their relative heat exceeds that of common air, and each
h gas has a distinct index to express its relative heat; so the
antity of caloric they contain exceeds that contained in an
al volume of atmospheric air.

The capacity of atmospheric air is assumed as the unit by
ich *to estimate the specific* heat of gaseous bodies; but some-

*Second Expt.* Throw one pound of iron-filings into 1 lb. of water at 32°, and the mixture will s 36° as soon as equilibrium is established. — That c of heat therefore, the loss of which lowers the temp of iron 32°, produces a rise in the temperature of only 4°; whence it is evident that eight times a caloric is requisite to raise or depress the temperatur water 1°, as would raise or depress the temperatu equal weight of iron 1°. Hence we infer the speci of iron to be $\frac{1}{8}$ or 0·125.

Expressing this law in general terms, let M be th of a mass of water, *t* its temperature, and C its cap heat; let *m* be the weight of the hotter substance to be examined, T its temperature, *c* the capacity and T′ the temperature of the mass when mixed.

Then the quantity of caloric gained by the water MC(T′−*t*); for it is obvious that the quantity necessary to raise the temperature of a body any nu degrees must be proportional to its mass and capac like manner the amount lost by the body under inve may be expressed by *mc* (T − T′). But as bo expressions are equal to each other,

$$MC(T'-t) = mc(T-T');$$
$$\therefore \frac{c}{C} = \frac{M(T'-t)}{m(T-T')};$$

and putting the capacity of water = 1, the specific the body under investigation will be

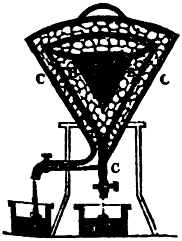
$$c = \frac{M(T'-t)}{m(T-T)};$$

This method, adopted by De Luc, Crawford, philosophers, is not altogether free from inacc during the experiment a portion of the heat is n lost by radiation, as well as by conduction to t and to the ambient air.

2.) The capacity of substances is found by obser *quantity of ice* the body under investigation is capable of This experiment is best performed by placing the subst *calorimeter*, and so completely surrounding it with ice.

The calorimeter (*fig.* 111.) consists of a vessel iron plates C, enclosing a smaller one B, and insid wire-cage A, intended to contain the substance amined. The space between the first and secon as well as that between the second and third, is

*Fig.* 111.



pounded ice. The ice in the outer space prevents the warmth of the external air from acting on the substance within, so that the ice around the wire cage is affected only by the heat emitted from the substance under investigation, which continues to thaw the ice until its own temperature is lowered to 32°. The water thus generated escapes by a cock $c$; at the close of the experiment it is weighed. To obtain the specific heat of liquids we must put them into vessels of known specific heat.—The principle on which this apparatus acts is this, that melting ice maintains invariably the temperature of 32° Fahr., and that all the heat applied to it is expended solely in thawing it.

From experiments which will be described in the next division of this subject (§ 402. expt. 2.) it has been ascertained that 135° of heat are necessary to melt 1lb. of ice; whence the mass of M lbs. of ice (equal to the weight of the water discharged) melted in the calorimeter must have deprived the body in the wire-cage of M times 135° of heat. Call the mass of this substance $m$lbs., its temperature above 32° when placed in the calorimeter $t$°, and its capacity $c$, then the quantity of caloric it contained would be $m\,t\,c$; but $m\,t\,c = 135\ \mathrm{M}$; whence the capacity sought is

$$c = \frac{135\ \mathrm{M}}{m\,t},$$

*ex. gr.* 2lb. of iron at 122° in cooling to 32° melts $\frac{1}{8}$lb. of ice; whence

$$c = \frac{135 \times \frac{1}{8}}{2 \times 90} = \frac{1}{8}.$$

This method, which was adopted by Lavoisier and La Place, is available for solids and liquids; it gives results more accurate than the former, but requires extreme precision in conducting the experiment.

3.) *By cooling the substance.* The principle on which this method depends is this — that the more slowly a body cools the greater must be its capacity for heat; for it must have parted with a greater quantity of caloric, to give out which the longer space of time was required. In this case it is necessary to nclose the substance to be examined in a shell which has the ame *constant radiating* power.

To effect this, the body which is the subject of ou investigations is placed in a pulverized or fluid condition in polished metal vessel (a cylinder of thin silver is best), and the time is noted which elapses before it falls from som particular temperature any certain number of degrees. I one substance cool as rapidly again as another, then the specific heat of the former is only half that of the latter; whence by the preceding section we can readily find the specific heat.

This method was first invented by Mayer, it was subsequently improved upon by Leslie, and has been carried to a high degree of perfection by Dulong and Petit.

The specific heat of gases cannot be ascertained by any one of the three methods yet described. Delaroche and Bérard used for this purpose *Rumford's water-calorimeter*, a vessel filled with water through which a spiral tube is conducted. The gas to be examined is first heated and is then brought from a vessel surrounded with boiling water at 212° gradually through the worm of the calorimeter, from the open end of which it escapes. In the course of its passage the gas parts with a portion of its caloric to the cold water which surrounds the worm, the temperature of this fluid gradually rises until after the lapse of some time it becomes stationary. The equilibrium thus established between the water and the gas is measured by means of a thermometer, so that we find both the rise in the temperature of the water and the fall in that of the gas. Now, if the experiment be repeated with some other gas, and the result should give a higher temperature to the water, then this second gas must have imparted to the fluid a greater amount of caloric than the former one did; if, on the contrary, the temperature of the water be less this time than before, it will have given out less caloric, and the respective capacities for heat of these two gases will be proportional to the temperatures of the water through which they have been conducted. If the capacity of atmospheric air be assumed as the unit, the specific heat of other gases may be expressed by proportionate numbers.

To raise 1 lb. of water from 32° to 212° we require the same quantity of heat as would have raised 4 lbs. of atmospheric air the same number of degrees. The specific heat of air is therefore ¼th, or more exactly 0·2669, that of water.

## § 396.

The capacity of both solids and liquids is not constant, b varies with every change in their density. Their capaci increases when the density decreases, and vice versà, whether th caused by mechanical means, or by a rise or fall in ature of the body, but in a less degree than their ue, that is to say, more caloric is requisite to raise a 212° to 213°, than from 32° to 33°. This increase capacity for heat may be accounted for on the assumpbut a part of the heat gained by the body tends to temperature, and that the remainder is consumed in e change in its volume.

ong and Petit, found as a mean of numerous experithe capacity of

| | From 32° to 212° | to 572°. |
|---|---|---|
| ry | 0·0330 | 0·0350 |
| a | 0·0335 | 0·0355 |
| ony | 0·0507 | 0·0549 |
| | 0·0557 | 0·0611 |
| | 0·0927 | 0·1015 |
| r | 0·0949 | 0·1013 |
| | 0·1098 | 0·1218 |
| | 0·1770 | 0·1900 |

like manner the capacity of coal and charcoal dies as its density increases. Regnault found that of

| | |
|---|---|
| al | 0·2415 |
| from Cannel coal | 0·2030 |
| lead from gas retorts | 0·2036 |
| nd | 0·1468 |

acity of gases for heat varies in the same manner as ls and liquids, viz. it increases when they are rarefied, hes when they are condensed; it diminishes therefore are subjected to an increased pressure; but these re not correspondent to the degree in which the conr rarefaction obtains. For atmospheric air, for instance, ly one-tenth greater capacity for heat when its reduced one half, and it must be rarefied 18 times, in ouble its capacity; if the air be condensed this ll be diminished in the same ratio as it was increased ction. In order to elevate the temperature of any gas 1°, supposing it to be perfectly free to expand, e pressure on it remains constant, a larger amount of be needed than if it were constrained by pressure to olume unaltered; *i.e.* in other words, *the specific heat of onstant pressure exceeds their specific heat when their rmanent.* — Dulong found by experiments based on nt velocities with which sound travels in gases of nsities, that in the case of the simple gases and their , the ratio between their specific heat under the same *d with the* same volume is as 1·421 to 1.

VIII. Vol. I. p. 185.), it obeys the hydrostatic law and rises to the surface, where a coating of ice first forms itself, through which, as ice is a bad conductor, the free caloric can with difficulty penetrate. Under a mean latitude the thickness of ice never exceeds from 1 to 3 feet; under higher latitudes it is not more than from 3 to 6 feet, and even in the coldest regions it is not more than from 10 to 12 feet. Lakes and seas whose depth exceeds these dimensions are therefore never frozen to the bottom. When the ice thaws we derive an opposite advantage from this property of heat. Were not so large a portion of caloric rendered latent during the process of thawing, the entire mass of ice and snow would be dissolved as soon as the temperature rose above 32°, and the most fearful inundations would ensue; in fine, but for the latent heat of water the variations in temperature to which the earth would be subject would render it altogether unsuitable for the habitation of man.

The application of heat from an external source is not always indispensable in order to liquefy solid bodies: many substances undergo this change of form if they merely come in contact with a liquid. Nearly all the crystallized salts possess this property. If a mixture be made of one of these salts with snow, or with some other liquid, the action of these substances on each other will convert one or both of them into liquids, one portion of their free caloric being consumed in effecting this change, as also part of the heat of the vessels containing the mixture. The consequence is, that the greater the degree of cold generated during the liquefaction of the mixture, the more quickly will the liquefaction be brought about, and the greater will be the quantity of heat taken up and rendered latent by the substance composing these *freezing mixtures*.

The following experiments will serve to illustrate t principles laid down above: —

*First Expt.* Place a thermometer in a glass, into whi throw some finely pulverized sulphate of soda (Glaube Salts) and some chlorate of ammonia, or nitrate of potas (saltpetre). — Shake the mixture and the thermometer w indicate a considerable depression of the temperature.

*Second Expt.* One part nitrate of ammonia and 1 water at 50° mixed together produce a cold of 5°; or parts of chlorate of ammonia, and 5 of nitrate of potass with 10 parts of water at 50°, lower the temperatur to 10°.

These salts may be crystallized again, and they will equally available for use.

*Third Expt.* Five parts of hydrochloric acid poured on 8 parts of freshly pulverized sulphate of soda reduce the temperature from 50° to 1°.

Water placed in thin glass vessels or tubes, and set in the mixtures named in this and the preceding experiment, is very quickly converted into ice.

*Fourth Expt.* One part of snow or pounded ice and 1 part of chloride of sodium (common salt) reduce the temperature from 32° to 1°.

*Fifth Expt.* Two parts of snow and 3 of finely powdered. crystallized chloride of calcium generate a cold of – 49° In this freezing mixture mercury, liquid ammonia, and æther will crystaliize.

Thilorier produced an extreme degree of cold by mixing solid carbonic acid with sulphuric acid or sulphuric æther; its intensity was such that it was equal to from – 110° to – 121°. Mitchel on repeating the experiment found that alcohol of 0·798 specif. grav. at – 130° acquired the consistency of oil, and at – 146° it resembled melting wax.

To ensure success in performing the experiments described above, the following particulars must be observed :—

1.) The salts must not have lost their water of crystallization, because in that case if they are so completely dried as to be in a state of efflorescence (§ 75.) they absorb so readily the first portion of water and convert it into crystallized ice, that a considerable quantity of caloric is thereby set free; sulphate of soda is a salt that effloresces readily. 2.) The salts must be finely pulverized that they may dissolve in the fluids as quickly as possible. Above all, care must be taken that, 3.) Too much heat is not communicated from without by means of the vessel containing the mixture. To guard against this, a sufficient quantity of the ingredients must be used; and if the temperature of the ambient air be not low enough, and if it is further desirable to maintain this extreme degree of cold in the mixture for some length of time, it is necessary to fill a large vessel with some freezing mixture and to place in it a smaller vessel also filled with the frigorific substances, setting in this inner vessel the particular substance we wish to freeze. The large outer vessel should be made of some bad conductor, such as wood, clay, or the like; but the inner one in which the cold is to be generated should be made as thin as possible and of a good conductor. — Walker adopted the following neat contrivance for freezing water. His apparatus consisted of a wide tin cylinder with thick sides, enclosing a second with thin sides of equal height with the outer one. The second vessel consisted of two concentric cylinders fastened

| | | |
|---|---|---|
| Hydrochloric acid, below | - | −40 Pouill |
| Sulphuretted carbonic acid | - | −49 Parry. |
| Sulphuric æther | - | −146 Mitche |
| Alcohol | - | −148 (?) Thi |

## § 404.

Non-elastic fluids and many solids in a state of fusion, their temperature rises, acquire an increased repulsive among their molecules, and assume the gaseous form. peculiar undulatory movement of the liquid, caused by ascent of the elastic fluid that is generated, is called *ebullitio* *boiling*, and the gas is termed a *vapour* or *steam*.

The *boiling point*, or the temperature at which ebullition c mences, varies in different fluids, and, indeed, in the same fl according to the pressure to which it is subjected. This press is principally caused by the atmospheric air, and by the aque vapour it contains; in a less degree it is owing also to the weig of the superincumbent strata of the fluid itself.

When the expansive force of steam exceeds this pressur ebullition begins throughout the mass.

*First Expt.* Half fill with distilled water an extremel thin glass which place in a sand bath, to avoid the risk of the glass flying; place the whole over a spirit lamp, immersing the bulb of a thermometer in the water; the thermometer will rise continually as more and more heat is imparted to the water. After some time a quantity of minute bubbles will be seen to attach themselves to the sides of the vessel, then gradually to rise to the surface o the water, and immediately vanish. These are in fact the gas contained in the water, principally indeed atmospheri air, which disengages itself from the heavier fluid as th temperature rises. (See § 57. *Second Expt.*) As the mercur rises towards 212°, fresh air-bubbles ascend, principally fro the bottom of the glass to the upper strata, which, not bein yet raised to a sufficient temperature, receive addition heat from these bubbles until at length a perfect equality established in the temperature of the fluid. Steam th begins to be generated, the formation of which may known by a peculiar hissing sound, which just precedes t ebullition of the liquid. Lastly; when the entire mass water has attained the requisite degree of heat, larger a larger bubbles of steam rise to the surface, where they bu and produce the undulatory movement known as ebullitio This last stage of the process is reached when the th mometer has risen to 212°, beyond which point it does not ascend, whatever the additional quantity of heat imparted, the continued application of which will diminish the water until it shall have completely disappeared. On this fact, the fixity of the boiling-point of the thermometer depends. (§ 366.)

The boiling points of some of the most important liquids, and that of certain solids, when in a state of fusion, are given below, the altitude of the barometer being 29·92196 inches.

| | Fahr. | |
|---|---|---|
| Sulphurous acid boils at | 14° | Bussy. |
| Muriatic æther | 54 | Gehler. |
| Nitric æther | 69·8 | Dumas. |
| Sulphuric æther | 95 | Munke. |
| Acetic æther | 165·2 | Dumas. |
| Alcohol, absolute | 173·1 | Gay Lussac. |
| Water, pure | 212 | |
| Vinegar, common | 212 | Mollerat. |
| Hydrochloric acid | 220 | Bineau. |
| Nitric acid, spec. gr. 1·42 | 249.4 | Dalton. |
| Oil of turpentine | 312·8 | Dumas. |
| Sulphuric acid, common | 550·4 | Davy. |
| Linseed oil | 600·8 | Murray. |
| Mercury | 680 | Mitscherlich. |
| Camphor | 219·2 | Dumas. |
| Iodine | 347 | Dumas. |
| Phosphorus | 554 | Mitscherlich. |
| Sulphur | 600 | Mitscherlich. |

With regard to the temperatures given above, as expressing the boiling points, these vary according to the purity of the liquid; thus, *ex. gr.*, solutions of salts boil at higher temperatures than water does; mixed fluids in like manner boil at different temperatures, according to the relative proportions of the substances composing the mixture. In many solutions of this class ebullition is attended with such violent jerks, that the thermometer can with difficulty be kept steady. Legrand observes that this inconvenience may be remedied by dropping a small piece of iron or zinc into the boiling liquid. Should this not abate the violence of the disturbance, drop in a piece of platina or glass.

One remarkable phenomenon connected with these fluids, and especially with water, is, that if placed in minute quantities on red-hot plates they do not boil, nor yet do they evaporate quickly, but, as the metal begins to cool, they

heat, by heating it over a spirit-lamp.
[illegible] of a glass tube, introduce a dro
the hot metal. The liquid will assume a gl
like a drop of mercury, and will begin to re
velocity, without boiling, during which pe
will very slowly diminish. Remove the lamp
will soon cool; in a little while it will fall to a
which the drop of water it contains will eit
or will fly apart with a small explosion. I
represent the stellated forms of the drop at
ment of its gyrations, the size of the drop at
about half an inch. The excursions it pe
the curves described by the luminous speck
place (§ 124), and show plainly that the
fluid are in a state of vibration.

Up to the present time these phenomena
quite satisfactorily accounted for; as for
oscillatory movement they warrant the inf
phenomena of heat are a consequence of
the æther and of the constituent particles of

The more the pressure at the surface of any fl
the higher does the boiling point ascend; on the c
this pressure, the lower the point at which ebulli
is owing to the atmospheric pressure that many
such at ordinary temperatures; we may cite, as i
the various kinds of æther, &c.

Experiments 1 and 2 (§ 196.) may serve

fluid being a vacuum; if one ball be grasped in the hand the liquid in the other will begin to boil violently.

The diminution in the atmospheric pressure is the occasion of water's boiling on high mountains at a temperature which is lower, just in proportion to the elevation of the mountain, or, what is the same thing, to the barometric altitude. (§ 202.) The following little table will exhibit at one view the boiling point of water at some of the principal elevations: —

| Station. | Height in feet. | Heat of Barom. | Boiling Point. |
|---|---|---|---|
| Mont Blanc - | 15773 | $17\frac{1}{20}$ in. | 187·7° |
| Peak of Teneriffe | 11936 | $20\frac{17}{100}$ | 190 |
| Quito - | 9485 | $20\frac{78}{100}$ | 194 |
| Hospice of St. Bernard | 8173 | $21\frac{1}{20}$ | 198 |

At such considerable elevations the heat of water boiled in open vessels is not sufficient to soften animal fibre, for which reason the inhabitants of these regions use Papin's Digester to prepare nutritious food. This apparatus consists of a close metal vessel, provided, for the sake of safety, with a valve to allow the escape of the superabundant steam. The accumulation of steam increases the pressure on the surface of the water, and thereby prevents its ebullition until a higher temperature has been arrived at than can be attained in the open air.

As the elevation of a place above the level of the sea may be found by knowing the amount of the atmospheric pressure (§ 202.), and as the point at which water boils will be lower the less this pressure, it follows that its amount may be determined from the height of the boiling point. Hence the truth of Wollaston's experiment for using the thermometer as an instrument for measuring altitudes. If the temperature at which water boils = $t^\circ$ Cent., the height of the barometer in metres may be found by the formula: —

$$^{*}\ \log.\, b = \frac{29{\cdot}945371\, .\, t}{800 + 3\,t} - 2{\cdot}2960374.$$

Lastly; from the above we see why, in determining the boiling point of a thermometer, reference is always had to the height of the barometer at that time, and consequently a correction is necessary if the mercury be above or below the standard height. (§ 371.) For every line above 28 Paris inches the scale must be shortened 0·0011 of its length from

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[*] NOTE. The formula in English standards may be found in Tredgold on the Steam Engine, p. 59. thus: —

The following experiments will confirm the truth of what has been just advanced: —

*Second Expt.* Wrap some muslin, cotton, or wool, round the bulb of a thermometer, and plunge it in spirit of wine, sulphuric æther, or sulphuretted carbonic acid; as the envelope dries by the evaporation of the liquid with which it is saturated, the temperature of the thermometer falls. The mercury will descend still more rapidly if the thermometer be moved quickly to and fro through the air, or if a current of air be directed on the bulb by blowing a pair of bellows. — If sulphuric æther be used, the thermometer will fall even in summer below the freezing point; and with sulphuretted carbonic acid it soon descends from 67° to 0°.

These effects are exceeded by the still more rapid evaporation of liquid sulphurous acid, by means of which Bussy has succeeded in congealing the mercury in the bulb of a thermometer in the open air. If this acid be carefully dropped on water, the latter will instantly be covered with a thin film of ice.

*Third Expt.* A few drops of spirits of wine, or sulphuric æther, let fall on the back of the hand, evaporate quickly if the hand be moved backwards and forwards, and a sensation of great cold will be produced on that spot.

The sensation of cold experienced on coming out of a bath, or on being wet with rain, is owing to this combination of the latent heat with the fluid as it evaporates. By the same means ice is made artificially in the East Indies; so also water is cooled in Spain, in porous earthen vessels, called alcarrazas. Wine, too, is cooled on board ship by wrapping wet cloths round the bottles, and hanging them up so as to be exposed to a current of air. — The cooling of cannon by wiping them out with the sponge is mainly owing to the rapid evaporation of the water caused by the heated metal. — The evaporation by perspiring enabled Fordyce, Banks, Solander, and Blagden to continue for 8 minutes in a chamber heated to 257°. In the Austrian salt-mines the men work at a temperature of 240° in those chambers where the salt is dried; and in some furnaces and blast-houses the workmen are exposed to still greater heat without their bodies being heated much beyond the normal temperature.

Even in the height of summer an intense cold may be generated if we accelerate the evaporation by rarefying the air, and especially if we make some arrangement by which the vapour that is thrown off may be absorbed by some other body. This may be verified by the following experiment: —

*Fourth Expt.* — *Leslie's Experiment.* — *Water frozen by evaporation.* Water at 68° by evaporation must absorb $36 + 972 + 135 = 1143°$ of heat.

Fig. 112.

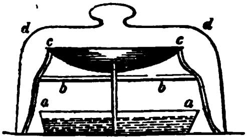

*Fig.* 112. represents the requisite apparatus. *a a* is a glass or porcelain vessel, about 5 or 6 inches in diameter, over which a little tripod stands, bearing a thin metal cup, *c c*, of about the same size as *a a*; the distance between these two should not exceed 2 or 3 inches. Fill the lower vessel with concentrated sulphuric acid, and the upper one with the water you propose to freeze; the aqueous vapour of the water will be absorbed by the acid. The whole apparatus is to be placed under a bell-glass on the plate of an air-pump, and the air is to be rapidly exhausted. When the barometer gauge stands at 2 lines, crystals of ice will shoot across the surface of the water; and if the external air be excluded from the receiver, the whole mass will soon be converted into ice. The water is elevated on a tripod, that the acid may not fall into it should the apparatus be shaken. — The successful performance of this experiment is considered as a pretty good test of the excellence of an air-pump.

On removing the bell-glass, after all the water has been frozen, it will be found that the sulphuric acid, though so near to the cup containing the ice, is considerably heated; whence it appears that the heat which the aqueous vapour abstracted from the water during its formation, and the loss of which caused the latter to freeze, has passed as free caloric to the acid which absorbed the vapour and reconverted it into the liquid form. — If the ice thus formed be left in the vacuum under the receiver, the continued evaporation will lessen its dimensions until it finally disappears.

*Fifth Expt.* — *Configliarchi's Experiment.* — *Mercury frozen by the evaporation of sulphuric æther.* — Since sulphuric æther in its conversion into vapour (§ 404.) absorbs 302° of latent heat, and liquid mercury contains 157° of the same, if both fluids have the temperature of 68°, then $302 + 157 + 36 = 495°$ of heat will become latent before the mercury is frozen.

The conversion of liquids or solids into vapour, and th reconversion into their former state of aggregation, is mad use of both for chemical and technical purposes. Wh liquids are changed into vapour by heat, and are then con densed again into liquids, they are said to be *distilled*. Th same process applied to solids is called *sublimation*; and th vapour which, by cold, is restored to the solid form, is call a *sublimate*. Both operations are of service, sometimes fo combining different substances, sometimes for separating on from others with which it is united. Fuller details belong rather to a treatise on chemistry. (Compare § 84.)

Many natural phenomena, a complete account of which i is the province of Meteorology to give, are consequences o condensation by cold. Such are mists, clouds, rain, snow, hail, dew, and hoar-frost. — The moisture and the glazed frost, visible on windows, are also merely the aqueous particles of the air in a condensed state.

## VI. PROPERTIES WHICH DISTINGUISH STEAM AND VAPOUR FROM TH PERMANENT GASES.

### § 407.

*Steam* and *Vapour* are strictly homogeneous, and differ fro each other, as has been said already, only in the mode of the production. They are both generated by the action of heat e panding the constituent atoms of solid and liquid bodies, a causing them to repel each other. This change of form is u accompanied by any alteration in the chemical composition of t substances. Gaseous fluids differ one among another both ph sically and chemically, according to the body from which th are formed by its combination with heat. Thus we speak aqueous vapour or steam, of mercurial, sulphurous, and ot vapours. The most important of all, on every account, is stea Its properties only will therefore be treated of at length thro the remainder of this portion of the work.

It has been observed incidentally (§ 179.) that these gase fluids resemble the permanent gases in many respects, but i in others they differ widely from them. The principal poin distinction between them is this, that *steam, by a lowering o temperature, or by increasing the pressure on it, may be reduce its original form of aggregation, but that permanent gases canno thus acted on.*

## § 408.

So long as the temperature continues unchanged, only a certain antity of steam can be generated in a close vessel; as soon as becomes full of vapour, no more is generated by the liquid it ntains, provided that the same temperature is maintained. nder such circumstances the space would be said to be saturated ith steam, which is called either *saturated* steam, or steam *of aximum density.*

When applied to mechanical purposes, steam is generally used at its maximum density, for which reason there ought always to be in boilers and digesters a sufficient quantity of water completely to saturate the space they contain. The aqueous vapour held in the atmosphere is very rarely indeed in a saturated condition, being found so only in rain and dense fogs. Generally speaking, we may assume, if a vessel contain a liquid which is giving off steam, that that vessel is filled with steam at a maximum density.

## § 409.

The *density* of steam in this condition varies with its temperature, for, if that be raised, more of the liquid is converted into steam; the quantity of the latter, and also its density, are consequently increased. If the temperature fall, a portion of the steam resumes the liquid form; the quantity of steam and its density are diminished.

The relative density of steam, or its specific gravity, has been investigated experimentally, and it has been ascertained that the ratio of the density of saturated steam to the density of atmospheric air is a constant quantity, provided they are both under equal pressures and at equal temperatures. Gay Lussac has estimated the density of steam under these conditions, to be invariably 0·6235, or five-eighths of the density of the atmosphere. Comparing this with the density of water, it follows that that of steam at 212° is about $\frac{1}{1700}$ (or, more exactly, $\frac{1}{1683}$) of the density of water; that is to say, steam at this temperature would fill a space 1700 times greater than that of the water which produces it; 1 cubic foot of water (at its maximum density, § 376.) would be converted into 1700 cubic feet of steam at 212°.

The weights of bodies whose volumes are equal are as their densities, whence from the known or required density of the steam we may calculate its weight. Let $x$ be the

[illegible]

[illegible] elastic force [illegible] The degrees [illegible] table above [illegible] column of mercury [illegible]

## § 415.

[illegible] be inferred, from the remarks [illegible] resemble the permanent gases [illegible] them.

[illegible] now to consider what is the effect [illegible] upon either enlarging or contracting the space [illegible] vapour.

[illegible] suffers no change in its form [illegible] expansion or contraction of the space [illegible] density, and consequently its elastic [illegible] in the latter they are increased; and this [illegible] only as the change in volume.

[illegible] in a close vessel resembles a permanent [illegible] volume be increased, or the pressure [illegible] more rare; but the similarity [illegible] condensation consequent upon the diminution [illegible] increase of pressure, only to the point [illegible] maximum density for the particular [illegible] this point has been reached, the least additional [illegible] contraction of space, causes a partial [illegible] into a liquid.

[illegible] Torricellian tube in Dalton's experiment, which [illegible] in the preceding section lower in the vessel [illegible] and the space above the mercurial column that [illegible] the vapour of that fluid which is being experi[illegible] will be diminished; and as this vapour is at a [illegible] density, so much of it will be reduced to the [illegible] equals the diminution of the space that con[illegible] The amount of the reduction will be shown by the [illegible] the length of the column of fluid supported by [illegible] of mercury, the height of the latter remain[illegible] Now, according to Mariotte's experiment [illegible] had the space above the mercury been occupied by air, the column of mercury would have become *shorter* when the tube was depressed in the cistern. Continue to depress the tube until the mercury rises almost to the closed end, and the whole of the vapour will be changed into liquid.

The following illustration may perhaps render the preceding observation more easily comprehended. Suppose a quantity of vapour at 212° to expand and occupy so large a space that its tension is reduced one half, *i. e.* till it equals only half an atmosphere; then, as the pressure diminishes, and the volume increases, rarefaction goes on precisely as in the case of atmospheric air. Next, if it be subjected to the converse operation, we shall find that it may be compressed till its expansive force again equals 1 atmosphere, that being the maximum for steam at 212°; but if the process be continued beyond that point, *ex. gr.*, till its volume is reduced one half, then one half of the vapour will resume the liquid form, but the other half will still be vapour, with a maximum expansive force of 1 atmosphere. Thus a permanent and progressive pressure might convert the whole mass of steam into liquid.

## § 414.

ses and vapours are not affected by *heat* in precisely the manner.

ery gas enclosed in a space acquires an increased expansive (§ 377, 378.), corresponding with the index of its expansion temperature be elevated; and conversely, the expansive force portionally diminished if the temperature of the gas be ed. The limits have not yet been ascertained to the increase rease of this force.

w, the elevation of the temperature of a mass of vapour ed in a space is affected precisely as a mass of any elastic vould be; that is to say, its tension increases; but if its temre be lowered, its expansive force will gradually become whilst, at the same time, a corresponding portion will lose rm of vapour and be converted into a liquid.

Suppose a certain space to be filled with steam at 212°, hen at a maximum density its expansive force will equal 0 inches, or 1 atmosphere. Cool this mass to 180°, and ts maximum tension will be lowered to about half an atmophere; and so much of the steam will have been converted nto water, that the remaining portion filling the space unccupied by the water will have a tension of 0·5 of an atmo-

## VII. APPLICATION OF STEAM TO MECHANICAL PU

### § 419.

In modern times the application of steam to mec
poses has become increasingly varied and extensive
quently the part it performs in the different de
industrial life is of growing importance. Undc
greatest service it renders is by its expansive force, a
*steam engine.* The considerable amount of both fre
caloric (§ 404.) it contains, is employed in *drying b*
in heating rooms and drying goods. The solvent po
above the temperature of 212° is made use of in
kinds of *apparatus for cooking by steam*, besides bein
other cases to soften or dissolve solid bodies.

One of the most simple pieces of apparatus fo
both the mechanical and thermal properties
the *steam globe*, or *aeolipila* It consists of a h
of copper or brass (A, *fig.* 120.), about 3 or
diameter. The aperture *a* serves partly for int
liquid, from which the steam is to be raised
for screwing on different curved tubes, as o
require
mouth
issues.
aeolipil
half fu
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the flui
boiling
To g
the risl
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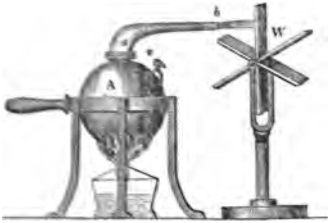
the sphere with a safety-valve *r*.

*Fig.* 120.



The following experiments will show the e
propelling forces acquired by the steam.

*First Expt.* Let the steam of the boiling
issues from *b*, inpinge against the vanes of a w
turns readily upon its axis; the vapour will
force as to impart a rapid rotatory motion to t

*Second Expt.* Give to the steam tube such
as is represented in *fig.* 121. ; but instead

vessel with water, use spirit of wine, and its vapour as it issues from *b* will act upon the flame of the spirit lamp, like the blast of a blowpipe, and give it such an intensity that glass and several of the metals will be melted by its heat.

*Fig.* 121.

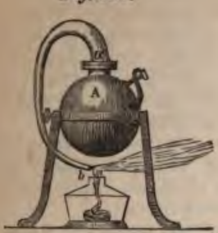
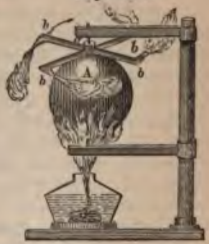
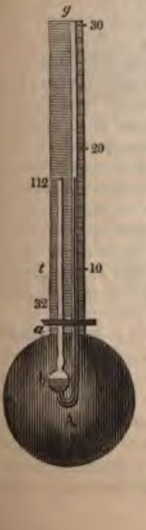


*Fig.* 122.



*Third Expt.* Provide the aeolipila with an axis about which it may turn (*fig.* 122.), and give to the tube *a b* the form shown in the diagram, and you will have precisely the apparatus invented by Hiero of Alexandria, 120 B. C.; the steam will escape in a direction tangential to the axis; and the reaction caused by its emission will generate motion in an opposite direction, the rotation of the ball depending on the same principle as that of Segner's machine, explained in § 165.

*Fig.* 123.



On the opening *a*, *fig.* 123, screw a barometer tube *b g*, instead of the steam-pipe; this barometer-tube will serve the purpose of a manometer (§ 200.), and show the increased tension of the steam attendant on an increase of the temperature. To effect this, the thermometer *t* is fixed beside the barometer-tube, its bulb descending into the space filled by the steam, the heat of which it therefore indicates. The expansive force or tension of the steam will be measured by the height to which the column of mercury rises in the barometer-tube, whose cup *b* should contain such a quantity of quicksilver as would suffice to fill the whole of the tube. To the mercurial column supported by the steam add the altitude of the barometer, at the time of the observation, and the sum of these two altitudes wi express the expansive force of the steam, which answers t the temperature shown by the thermometer.

By means of the same apparatus we can investigate th thermal properties of steam.

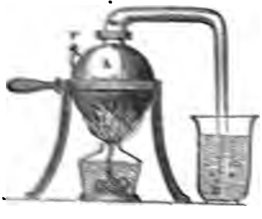
*Fifth Expt.* Allow the steam to issue from the stea tube into the open air, and a portion of it will be condense and rendered visible in consequence of its giving out som of its caloric to the surrounding atmosphere; extremel minute bubbles will be formed, which are filled with humi air enclosed in a thin film of aqueous vapour: these will b borne along by the air like aerostats.

Conduct this stream over a hot metal plate, or over som burning charcoal, and it will cease to be visible, because n absorption of its heat takes place, and consequently there i no condensation of the steam into water.

*Sixth Expt.* Now receive the current of steam on an cold body, as a plate of metal or a glass receiver, and th aqueous vapour will be deposited over the surface in th form of water, and the metal or glass will be rendered per sensibly warmer by the heat which has been liberated.

The same result follows if the steam-pipe be conducte as is shown in *fig.* 124., so as to terminate in a vessel c water. The steam is instantly condensed, so that the vapou which is emitted at *i* disappears instantaneously withou rising to the surface in th form of air bubbles. Th water in the vessel becom gradually heated, as m be seen if a thermomet be immersed in it, until length it reaches the boili point. This experiment m serve to show indubitab the great quantity of late heat contained in stea although it does not furni us with the means of exac measuring its amount.

*Fig.* 124.



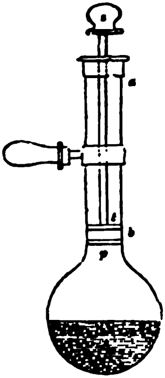
## § 420.

The *steam-engine* is unquestionably one of the most importa it is one of the most useful, inventions of the eighteer tury. The principle on which it acts is this, that steam at mperature exceeding that of boiling water possesses so great pansive force (compare § 410. and Tables XII. and XIII.) as propel bodies against which it is directed, such bodies returnng to their original position when the steam by being condensed deprived of this force.

This fundamental action of steam, which is made use of in the working of every variety of steam engine, may be illustrated by the following simple apparatus:—

*Expt.* The arrangement consists of a glass tube (*a b*, *fig.* 125.), open at one end and enlarged at the other into the bulb A; a piston *p*, surrounded with worsted or cotton thread, saturated in grease to render it steam-tight, is worked up and down by means of the piston rod *t s*. — Place some water in A, and hold it over a spirit lamp till it begins to boil, the steam thus generated will elevate the piston *p* to the upper end *a* of the tube. — Plunge the apparatus in some cold water, the steam will be condensed, a vacuum will be formed beneath the piston, and the superincumbent pressure of the atmosphere will drive down the piston to the lower part of the tube.

*Fig.* 125.



The principal parts of every steam engine are the *boiler* and *cylinder*: in the former is placed the water which it is intended to convert into steam, and in the latter is the *piston*, which is to exert the motive power. Besides these principal parts of every engine there are many mechanical contrivances, by which the former are connected, and by means of which the entire working of the machine is regulated, and the motive power applied in the desired direction.

Various forms have been given to the boiler, which is made of the very strongest wrought iron; sometimes it is of a spherical figure, sometimes like a trunk with a rounded lid, most generally however it is cylindrical: in some cases it consists of a number of tubes connected together, this construction having been adopted to lessen the risk of explosion. It is filled with water to a certain height, above which is the space where the steam is to accumulate; beneath the boiler is the furnace for heating the water. The boiler and cylinder are connected by means of the *steam-pipe*, by which steam is conveyed from the former to the latter; a second pipe, called the *feed-pipe*, keeps up a supply of water in the boiler, to make up for what is abstracted in the form of steam. *Appliances* of a more complicated nature than we

the observation, and the sum of th
express the expansive force of the s
the temperature shown by the therm

By means of the same apparatus
thermal properties of steam.

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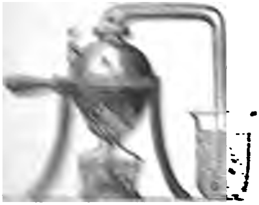
Fig. 124.



[illegible]

§ 430.

[illegible] is unquestionably one
[illegible] the most useful, invent
[illegible] The principle on which it acts
[illegible] exceeding that of boiling wa

their size was only such as fitted them to discharge small shot; that a considerable time must elapse before the steam attained the necessary force to effect the discharge; and lastly, that the force of percussion attained by the balls was less than that of similar balls projected by means of gunpowder. Prechtl, in his Jahrbuch, d. K. K. polytechn. Instit. zu Wien ix. 1—42., has demonstrated that the effect of steam, under those circumstances in which it has yet been found, is not equal to that of gunpowder when applied to large shot.

The great superiority of steam over every other motive power is this, that, provided we can have the necessary fuel and water, we can apply it to any point we desire, and within pretty extensive limits we can increase or diminish its force. It can be applied with great advantage in circumstances where other motive powers, water-power especially, would be inadequate to perform the duty required, or insufficient and uncertain in its supply. If we compare, in an economical point of view, steam and water power, we must be guided in our decision, not merely by the original outlay or the actual cost of working the two powers, for in respect of original expenditure water will probably be the more costly, and the cost of working it small; whereas, the steam-engine, if cheaper in the first instance, entails a permanent expense. If, however, a regular and uninterrupted force is wanted, as in mining operations, navigation, many kinds of manufactures, &c., then the steam-engine has a decided superiority over water-power in its greater regularity and certainty; and unless, which is rarely the case, the supply of the latter is both constant and equal, it is ill suited for these purposes. If the work required to be done is uncertain in amount and irregular as to time, so that the furnace would have to be lighted and fire extinguished frequently, then the great expense which would be incurred would render water-power preferable. Many circumstances would contribute to decide the choice in favour of the one or other kind of engine, such as the purpose to which the engine is to be applied, the situation where it is to be erected, the cost of fuel, &c.

The older sort of *atmospheric engines*, working at low pressure, are very well adapted, where fuel is cheap, to raise water from mines, to supply towns with water, and to elevate any great masses of water. Indeed, their mechanism is extremely simple; they can be put up, and, when necessary can be repaired with greater ease than engines that work b the pressure of the steam. If made of small dimensions, the useful effect is insignificant, as the relative consumption coal greatly exceeds their effect if the cylinder be less than 25 inches in diameter.

*Single-acting steam-engines*, in which the piston is driven one way by the pressure of the steam, in consequence of their mode of acting, are available only for elevating water and performing that kind of work which is not impaired by the suspension of the power during the return of the piston. Generally speaking, their useful effect is not greater than that of the ordinary atmospheric engines; but their consumption of fuel is only one-third or half as much, and the quantity of water required for injection is also less.

The *double-acting steam-engine*, of which we have already given a detailed explanation, is best adapted for general purposes, and for accomplishing those performances to which the steam-engine is applied: hence of stationary engines this is the kind in most general use. The movement of this engine is extremely regular, for which reason it is well suited to drive mill-work, looms, &c., where the greatest attainable regularity in the performance is desired. The only limit to their adoption is, that there should be a facility for obtaining the requisite amount of water for injecting. These engines work with a smaller cylinder and consume less fuel than the single-acting engines. Their useful effect is greater, as the whole of the steam pressure is used in working the machine. They have been applied with complete success to propel large steam-vessels which were formerly believed to require high-pressure engines.

Machines that work by *expansion* require still less fuel than Watt's double-acting engines without expansion, as with an equal consumption of fuel they perform nearly twice the duty of the latter; and even if the expansive force of the steam is partially used in the latter, yet these engines will even then do half, or at least one-third, as much more. Their force may also be increased at any time, provided that the steam is not already at its greatest expansive force. This cannot conveniently be done with the double-acting engine. These advantages are counterbalanced by this drawback, that they are suited only to produce rectilinear motion, as the stroke of the piston is not performed uniformly; and if their movements were to be equalised by means of a fly-wheel, it must necessarily be of such extreme dimensions as would render its use objectionable. Besides, these engines are more complicated in their construction, and, consequently, more expensive in the first instance, as well as more likely to get out of repair, and more difficult to mend. For these reasons they have been less generally adopted, and in England have *almost entirely* ceased to be used.

All *high-pressure* non-condensing engines are, as res their mechanism, far more simple than the preceding. occupy less room, and are the lightest made. Their sumption of fuel is, however, the greatest. They are plied advantageously in all cases where space is an o and when the water requisite for condensation cannot be or can be had only at an undesirable sacrifice of po Their most extended application has of late been in l motive engines, whose piston-rods are connected immedi by means of cranks with the working-wheels, by whos hesion to the ground the load is propelled. In these en the boiler and furnace are arranged so as to generate s of high pressure in the least possible time. For every h power they weigh from 13 to 15 cwt., or about half as m as a double-acting steam-engine weighs. The original of stationary non-condensing high-pressure engines is than that of condensing engines; but the expense of wo them is greater. Their effect is no greater, and their b are much more liable to burst, which generally ha either through the steam being allowed to acquire a cessive expansive power, or through some irregularity supply of water. When local circumstances will admit sometimes convenient to apply the waste steam of engines to heat water for drying apparatus, or for wa rooms. High-pressure condensing-engines, working al expansion, are more economical than the non-conde engines, or than either the atmospheric or the single- engine, provided only that the requisite supply of wat be readily obtained, and that its somewhat irregular ac not a serious drawback. These engines are frequently in steam-boats, where water for condensation can be se with the greatest facility.

The number of steam-engines is annually increasin rapidly progressive rate. Fifty or sixty years ago there not 100 in use; at the beginning of the year 1838, number was estimated at about 200,000, equivalent labour of about 4,000,000 horses. The incessant ext of lines of railway will call into existence a growing n of additional engines.

## § 421.

The performance of a steam-engine is generally measured amount of its horse-power. This unit of power dates fro first application of the steam-engine in England to raise from the mines, a work formerly accomplished by animal l ıeir performances were estimated by the useful effect one horse ould produce during the ordinary duration of his work (§ 28.). his dynamic unit has hence been termed horse power; to it arious values have been affixed, but generally it is now estimated s a force that would suffice to raise a weight of 33,000 lbs. a eight of one foot in one second of time.

In France a new dynamic unit has been adopted, viz. the force which would raise 100 kilogrammes per minute through a height of one metre; the simplicity of this mode of reckoning will be a recommendation wherever the decimal system of weights and measures has been adopted. It may be hardly needful to remark that the nominal value of horse-power does not coincide with the actual performance of the animal, as the number of hours that animal exertion can be continued is limited in a manner that steam-power is not, consequently we are not to suppose that in useful effect 20 horses could be substituted for an engine of 20-horse power.

The gross effect of a steam-engine is found from the superficial content, or from the diameter, of its piston, the pressure on the piston, and its velocity. The last-named element is determined by multiplying the height of the piston-rod in feet into the number of strokes it performs in a minute, a whole stroke being both the ascent and descent of the piston in the cylinder, its motion either way being reckoned as a half stroke. From the gross effect thus found deduct the power spent in overcoming friction and in first communicating motion to the various parts of the engine. A further allowance has to be made on the account of the resistance of the uncondensed steam in the condenser; in non-condensing high-pressure engines this drawback is reckoned to be equal to one atmosphere. Hence the *useful effect* of any engine is found by making all these deductions from its gross effect (1), and dividing the remainder by the dynamic unit.

1.) The amount of power lost in different engines depends very much on their construction; in atmospheric engines it amounts to 0·52; in single-acting and non-condensing high-pressure engines it is 0·4; in double-acting engines 0·368; commonly one-third is assumed as a mean.

The following example of the mode in which the effect of a double-acting steam-engine is calculated may perhaps serve to illustrate the preceding remarks: — Suppose the expansive force of the steam in the boiler to be equal to 1½ atmosphere, and the temperature in the condenser 102°, then the force of the steam in it will, by Table XII., be 2·21 inches $=0{\cdot}074$ of an atmosphere; hence the effective pressure of the steam on the piston is $1{\cdot}5-0{\cdot}074=1{\cdot}426$

many chambers, all to be maintained at an equal temperature, has the two great recommendations of accomplishing the desired object at a smaller expenditure of fuel, and without exposing the buildings to the risk from fire, to which they are liable when heated by the ordinary mode.

This method of heating by steam has been applied to the drying of gunpowder, by which the risks of explosion are greatly obviated.

As 1 lb. of steam at 212° would raise 1 lb. of water from 32° to 1004°, whilst the capacity of the atmosphere for heat is only 0·2669 that of water (See Table XI.), it follows that 1 lb. of steam at the above temperature would raise the temperature of 1 lb. of air at 32°, that is to say, of a volume of air 770 times that of the water, to $\frac{972}{0 \cdot 2669} = 3604°$; it would therefore raise the temperature of a volume of air $\frac{3604}{36} \times 770 = 77000$ times greater than the volume of the water up to 68°.

Clement states that his experiments have shown that, in the mild climate of England, the tubes ought to have a surface of 1·5 square foot adequately to warm a space of 100 cubic feet; that, in northern France and Germany, to warm the same bulk of air, there should be a surface of 1·66 square feet of piping.

## § 423.

We have already observed that steam is used to macerate, or even entirely to dissolve solid bodies; this it effects, partly by means of the great quantity of latent heat it contains when at a high pressure, partly by its elastic force, and partly also by the extreme minuteness of its particles and the readiness with which they move among each other: hence they are enabled to penetrate into the interior of the substances on which they act, for they are urged by an equal pressure in all directions, and the substances submitted to the operation of this force readily fall asunder in minute portions.

However varied the forms of the *apparatus for cooking by steam*, the principle on which they act is common to all. Generally speaking, they are constructed either so as to convey the steam, generated in a boiler, by means of tubes, immediately to the meat which is contained in closed vessels, or the tubes are made to go round the outsides of these vessels; sometimes high-pressure m is used, and at others that which is generated at the ordinary ing point.

The first application of steam in this way to culinary purposes was made by Papin, the inventor of the *Digester*, in the early part of the 17th century; in this instrument he heated water considerably above its boiling point, and converted bones to a jelly.

The solvent power of steam is applied with advantage to many purposes connected with the arts; in large establishments such as hospitals, barracks, &c. it effects a large saving in expenditure if the food be cooked by steam.

## VIII. THE VARIOUS SOURCES OF HEAT.

### § 424.

Experience proves that the heat existing upon our globe is erived from various sources: of these the principal are, the *solar ght*; the *change in the aggregate form of bodies*, their *capacity for eat*, and their *chemical composition*; *electricity*; the *terrestrial eat*; the *process of vitality*, and many *mechanical operations*.

### § 425.

The *rays of the sun* supply the greatest portion of the heat at he earth's surface: one convincing proof of this is, that if any ody be placed in the rays of this luminary, its temperature rises. The degree in which its temperature is elevated depends on the ngle at which the sun's beams impinge on its surface, on the uantity of light united in one point, on its colour, and on the bsorptive power of the body itself.

A body becomes heated the more intensely by the sun's rays he nearer the angle under which those rays fall upon its surface pproximates to a right angle, on attaining which the maximum fect is produced: hence the intensity of heat imparted to a dy corresponds with the intensity of its illumination. (§ 285.)

Hence we understand why the sun has greater power at noon than in the morning or evening of the day; also, why snow on the roofs of houses inclined towards the south is melted before that which lies horizontally upon the ground. In like manner, we can account, from the inclination of the earth's axis towards the sun in its orbit, for the high and nearly uniform temperature of the regions near the equator; the lower temperature and the variations in the climate of those parts nearer to the poles; as well as the warmth of summer and the cold of winter generally. These results are obviously affected by the length of time the light of the sun has been in operation: for we do not experience the greatest degree of heat exactly at noon, but a little after that time: so too the hottest part of the year is not when the sun is at the solstice, but a little after the longest day.

By means of the reflection and refraction of the sun's beams they may be so combined in a focus as to produce a heat sufficiently intense to melt or convert into vapour almost all known substances. On this fact depends the operation of burning lenses and mirrors, hence also they derive their appellation. (§ 511.)

It will suffice to mention the famous burning mirrors constructed by Archimedes, also the burning mirrors and glasses of Tschirnhausen and Buffon. Parker, of London, constructed a burning glass 3 feet in diameter, and having nearly 7 feet focal distance, which fused platina, nickel, iron, emerald, asbestos, and other incombustible substances.

One remarkable property of solar light, with regard to its power of exciting heat, is that this property seems intimately connected with its refrangibility; so we see the greatest thermal intensity in the neighbourhood of the red rays of the spectrum, on both sides of which its heating power diminishes. This peculiarity has been already noticed in the section on light (§ 351.), and in that part of this work where radiant heat has been treated of (§ 388.); for further particulars, therefore, the reader is referred back to those portions of the work.

The more transparent any body is and the better it reflect light, the less does it become heated by the sun's rays; and conversely, the greater its opacity and the rougher is surface, th more intense the heat that can be excited. The colours of bodie greatly affect the readiness with which they may be heated, th bright colours having the smallest susceptibility for heat, th darker colours a greater, but black the greatest; white has th least of all.

This is so well known a property of solar light that it wil suffice to adduce but one or two examples.

Our atmosphere, the most transparent substance wit which we are acquainted, is the least heated by the sun rays; glass is more so, and that in precisely the same degre in which it is inferior in transparency.

Polished metallic surfaces if exposed to the sun's rays, ar always at a lower temperature than such as are rough.

Franklin's experiment, with pieces of cloth of differen colours, is a good illustration of the influence of colour on body's susceptibility of heat. Lay several pieces of clotl of different colours on the top of some snow on which th sun is shining; after a little time the darkest coloured cloth will be found to have sunk lowest beneath the surface. — Hence we see why black clothing is hotter wear in summer than similar articles of dress of lighter colour. — Paint a box black inside, close it at top with a pane of glass, and expose it to the sun's rays, the heat in the inside of the box will exceed that of boiling water.

The influence both of colour and surface, as also of transparency, with regard to heat, will be most readily seen by using a differential thermometer in the manner described in the second experiment in § 385.

Other sources of light present to us analogous phenomena only in a lower degree, as has been proved by modern researches on radiant heat. (§ 387. and § 388.) Whether heat or the excitation of heat is an essential property of every kind of light or no, has not yet been positively ascertained; but that light can retain all its luminous properties though deprived of all heating power, we see in the case of moonlight., Melloni has proved that the solar light may be deprived of its thermal properties by passing it through a sufficiently dense stratum of water.

From the facts above noticed, it has been satisfactorily established, that light in general, and especially that of the sun, is one of the principal sources of heat. As yet no perfectly satisfactory explanation has been given of the connection between heat and light: this would require such an intimate acquaintance with the nature of both as it is plain we do not possess from the mere fact, that two antagonist theories still divide the scientific world as to the nature of both light and heat.

## § 426.

One process is continually in operation on our earth by which heat is generated, namely, the *changes of aggregation* bodies undergo, the *changes in their capacity for heat*, and their *chemical combination* and *decomposition*.

It has been explained in § 399. that, when a gaseous body becomes liquid, or a liquid becomes solid, precisely the same quantity of heat is liberated as was held in a latent condition under its former state. The converse obtains when the opposite transformation happens.

So, also, heat is liberated if a body's capacity for heat is diminished. (§ 398.) This occurs whenever a body is rendered more dense by external pressure, or when its capacity is affected by chemical influence. The converse takes place when these circumstances are reversed. (See *experiments*, § 398.) The liberation or *absorption* of heat will be accelerated in proportion to

the capacity of substances for heat: this happens
the volumes of the bodies are altered, or they assu
of aggregation, or the compound has a different ca
from that of its elements. Whenever chemica
condenses a body, as when it converts a liquid int
gas into a liquid, or whenever it lessens the therm
the newly formed compound, caloric is set free.
ment of heat in detonating substances (§ 77) form
to this general law; as for instance in the case
where the liberation of heat may be explained if w
to electrical agency, which greatly modifies chemi
The process by which we develop the most intense
as combustion. A general explanation of the theory
has been already given in § 77.; minute details belon
province of chemistry; we shall now merely addu
mental illustrations of the above remarks.

(1.) The term *pyrophorus* is given to such
by the absorption and condensation of the a
and other gases contained in the atmosphere,
and ignite.

*Expt.* Spongy platinum is a well-know
body: it absorbs hydrogen and oxygen so r
comes in contact with these gases, and then co
that its entire mass becomes red-hot, and the

This phenomenon may be excited by condu
of hydrogen from a blow-pipe, or even from a
der, filled with the gas, upon a small piece of

2.) Another example of the same kind is afforded in the heat generated by throwing water on quicklime. The development of heat is accounted for by the formation of a hydrate of lime, in which the water assumes the solid form.

3.) A mixture of water or ice with sulphuric acid produces a high degree of heat.

## § 427.

*Electricity* is one of the most powerful agents by which heat is roduced: of this we shall, however, speak at greater length in hat part of this work which is especially devoted to that branch f physical science, when it will be made evident that electricity ffects the most diverse processes of nature.

## § 428.

The *terrestrial heat* is the source to which the internal solid mass of our earth is indebted for its warmth. Modern research has placed it beyond all doubt, that the temperature of the earth increases the lower we descend below its surface. Experiments have been undertaken, chiefly in artesian wells and mines, the object of which has been to measure, at different places, the increase in this temperature.

Professor Reich of Freyberg, Marcet, De la Rive, Erman, and Magnus have conducted experiments of this kind. The instrument best adapted to this purpose is the *Geothermometer*, invented by Magnus. Although these researches have not yet enabled philosophers to ascertain the law for the increment in the heat, yet, taking the results at a mean, it would seem that the temperature rises 1° Fahr. for every 60 or 70 feet we descend below the surface; hence, at a depth of a few miles, the earth must be in a state of incandescence.

This heat is not the effect of the sun's rays, but is owing to me internal source. That such an internal terrestrial heat es actually exist we have pretty good reason for believing, for w else can we account for the many hot-springs which gush up om great depths below the earth's crust? How could the earth ve acquired its flattened form at the poles, had it not begun to volve when its mass was in a soft, if not actually in a fluid, ate? (§ 47.) If, now, we suppose that this fluid condition was ving to the action of heat, and that our planet was once in a ate of fusion, then, as the process of solidification was carried on, at would be continually liberated, and this emission of caloric ight last *for centuries*. . . .

The following may be named as instances of heat excited and liberated by mechanical means:—All solids, but especially the metals, may be heated by striking. A bar of iron may be made red-hot merely by hammering it. In the year 1834 some experiments were performed at Metz, to determine the effects of cannon balls discharged against masonry. It was found that the balls, as they sank into the limestone, of which the wall was composed, generated so strong a heat, that the surrounding stone seemed to have been burnt, and the balls themselves, for some hours, retained a sufficient degree of heat to burn any person who touched them.

Gases, by virtue of their extreme compressibility, may be considerably heated, and the degree in which their temperature is raised may even be calculated accordingly. (§ 396.) An illustration was given in the *first experiment* § 396. of combustion produced by a great compression of the air.

The combustion of different detonating salts and powders on being struck or even pressed.

The striking a light by means of a flint and steel.

Steel tools, such as gimlets, saws, files, &c., become hot when used.—Fire procured by savages rubbing together two sticks.—Friction is also the cause of the axles of carriages, the cranks of large machines, the sockets in which the axles of fly-wheels work, and the cords that pass over pulleys, becoming intensely heated, and sometimes firing. This effect of the friction is checked by applying some unguent to the axles and cranks of machinery, and moistening cords and wooden wheels.—The borers by which cannon are bored become so hot that they would blister the hands if touched.

## IX. CONCLUSIONS RESPECTING THE NATURE OF BOTH LIGHT AND HEAT.

### § 431.

In the early part of this chapter (§ 362.) we just glanced the opposite theories which have been entertained respecting t nature of heat; now having noticed some of the principal phe mena, we shall be better able to compare these theories, a observe how far the explanations they afford are satisfactory; the same time we shall have an opportunity for remarking t *striking* analogies subsisting between light and heat.

According to the older hypothesis these different phenomena were attributed to a material substance of heat, which closely resembled the matter of light, but which was supposed not to be identical with it. This material heat was imagined to be a very fine, highly elastic fluid, but destitute of the primitive properties of all other matter, such as weight, impenetrability, &c. All bodies, whatever, were supposed to contain this hypothetical heat in certain but unequal proportions, and especially substances were conceived to have for it a different and varying attractive force. Most of the phenomena that come under our notice may be satisfactorily accounted for on this hypothesis, but not all, as *ex. gr.* the fact, that radiation goes on at all temperatures; for it is an established fact, that heat radiates even from such bodies as have a lower temperature than the others by which they are surrounded. Again; the uninterrupted development of heat by friction and electricity are not satisfactorily accounted for on the corpuscular theory. Lastly; the great similarity subsisting between light and heat does not admit of so satisfactory an explanation as upon the undulatory hypothesis.

According to the second theory, which has been very extensively adopted, light and heat are really identical powers, which display themselves in different modes of operation, and which are convertible the one into the other. On this assumption heat would appear to us as light, if its motion were altogether free; but if the light were deprived of its free and rapid motion by the operation of other bodies, then we should recognize the same agent at work as heat. The phenomena which bear out this hypothesis are the following, viz. that light produces heat, not merely by concentrating it but also by preventing its radiation, in which case it will be absorbed by bodies. (§ 385.) All substances become luminous when their heat reaches a certain point, varying with the nature of the particular substance. Radiant heat in its motion obeys precisely the same laws with light (§ 380—389.), and probably would appear as light to an eye of greater delicacy than ours. Although this theory assumes that luminous phenomena are never to be found uncombined with those of heat, and that the latter are joined with them either as cause or effect, yet this assumption is not borne out by experience.

The third hypothesis, which steadily gains an increasing number of adherents, is compounded of the two preceding theories. It assumes the existence of an æther which serves as the substratum for the joint phenomena of both light and heat, which owe their origin to the vibratory movements of this imaginary fluid, exhibiting to us the phenomena of heat or light, according to the less or greater velocity with which the particles are set in motion. (§ 381. and 389.)

*Professor Baumgartner* expresses himself in the follow sphere of operation than the exertion of its attractive and repulsive forces would indicate; and that, probably, many a phenomenon is ultimately owing to magnetic influence, although the mode of its connexion with that force is unknown to us.

The existence of a magnetic power was known from an early date; but the ancients were acquainted only with the attractive properties of the loadstone, to which mineral they gave the name of *magnet*, probably from the circumstance of its being found in abundance in the neighbourhood of Magnesia, a city of Lydia, in Asia Minor. The method of making artificial magnets was discovered in the 14th century, and the science soon acquired increased importance on the introduction of the mariner's compass into Europe. The rapid advances which have since been made in every department of natural science have caused the laws of magnetic influence to be more closely studied; our acquaintance with the operations of this powerful and widely extended force has accordingly become much enlarged.

## II. NATURAL AND ARTIFICIAL MAGNETS.

### § 433.

Such bodies as possess the attractive power we have described above, are termed *Magnets*, they are known by their drawing towards themselves, though from different distances, iron, steel, nickel, and cobalt, as also such other mineral substances as contain a portion of iron in their composition. If the attraction is converted into absolute contact, the magnet will hold the other body with a force whose intensity depends on a variety of circumstances. If a magnet be placed so that it can move its mass freely, it will invariably assume a certain definite position with respect to the earth.

Magnets are either *natural* or *artificial:* the former are iron ores, often called *loadstones*, and are found either at or below the surface of the earth; the latter are commonly of steel, they are of various forms, and the magnetic properties are imparted to them by a process which will be described presently; they are named according to their shape and the manner of their combination. Those artificial magnets, which are constructed so as to move freely, and which will therefore take the certain determinate *position* already spoken of, are called *needles:* of the different varieties we shall speak particularly by and by.

The loadstone is a chemical combination of the oxide and suboxide of iron ($Fe.O, Fe.O_3$). It is found pretty extensively distributed, especially in the northern parts of the world, N. America, Norway, Siberia, &c. In many of these regions the mineral exists in such abundance as to form whole mountains, and, if regarded as a single magnet, must be one of prodigious power. Repeated experiments have, however, led to the belief, that the interior strata of this mineral do not possess any magnetic properties, but that its influence is limited to those portions which are exposed to the air.

We have already observed that artificial magnets are of various forms; if they be either cylinders, or parallelopipeds, they are called *bar magnets*; if curved in the middle, so as to bring the two ends near together, they form *horse-shoe magnets*; when several bars or horse-shoes are combined, the whole is called a *compound magnet*, or a *magnetic battery*; and sometimes, more simply, a *bundle* of magnets.

### § 434.

Both the magnet and the body it attracts exert a reciprocal influence on each other; that is to say, the magnet attracts the iron or other substance, which in its turn attracts the magnet.*

The following experiments will illustrate this fact: —

*First Expt.* Suspend a piece of fine iron wire by a thread, so that it may hang horizontally. — Present a powerful magnet to one end of the wire, and the attractive force of the former will at once be evident.

*Second Expt.* Suspend a magnetic needle in like manner; offer to it a large piece of iron, and the needle will follow the iron in this case as the wire did the magnet in the former.

### § 435.

Magnetic attraction will be transmitted unimpaired through both solid and liquid bodies, and through gases either rare or dense; iron and such other substances as are capable of being magnetized, form the only exceptions to this rule.

---

* **Note.** — Perhaps it would be more correct to say, that "the attraction, which is *apparently* between the magnet and a piece of iron, is *actually* between two magnets presenting to each other opposite poles." — Walker's *Magnetism, p. 394.* in Lardner's Cab. Cyclop. See also § 439. in this work.

the magnet exerts an influence is termed its *circle of magnetic influence*, or its *magnetic atmosphere*. This influence may be either transient or permanent, as it is induced in pure iron, or in iron containing a portion of carbon. — In this condition of induced magnetism the general law of magnetic attraction begins to operate (§ 437.), and the magnet and the other body exhibit a tendency to approach; whence we may infer that every case of magnetic attraction is owing to induction; thus, *ex gr.*, a piece of soft iron is itself converted into a magnet before it can be attracted towards a magnet.

The following experiments will illustrate magnetism by induction: —

*First Expt.* Suspend two small pieces of soft iron wire by a thread in such a manner that they may hang vertically side by side, and near to each other, as shown in *fig.* 129. by the lines *n s*. Now bring the pole of a powerful magnet close to the lower ends of the wires, and we shall see, 1.) that both the upper and lower extremities of the wires repel each other, and so bring the threads out of the perpendicular; and 2.) that the lower ends of the wir[illegible] show a tendency to approach a[illegible] touch the magnet presented to the[illegible] This phenomenon can however onl[illegible] be brought about when the lowe[illegible] ends of the wires have acquired a[illegible] opposite polarity to that of the magnet offered to them, whilst the upper ends have a like polarity with it: this is shown in the figure.

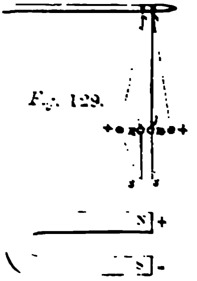
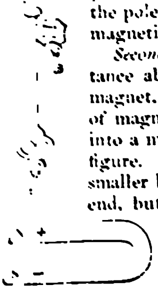


Fig. 129.

Substitute for the iron wire two common needles; these will be rendered permanently magnetic, their points having an opposite magnetism to that of the pole presented to them and their eyes the same magnetism with it.

Fig. 130.



*Second Expt.* Hold a large key at some distance above one pole of a powerful horse-shoe magnet, as represented in *fig.* 130., and by the laws of magnetic induction it will itself be converted into a magnet, having its poles as shown in the figure. Under these circumstances, it will carry a smaller key at its upper and another at its lower end, but if it be moved in either direction sideways, it will soon arrive at a point beyond the influence of the magnet, when the small keys will fall off.

## § 440.

We have already remarked that (§ 433.) magnets exert their attractive influence at various distances from bodies susceptible of it; that the intensity of this force consequently is not uniform, but that it varies with the distance.

> *Expt.* This may be easily shown by bringing a magnet near to a magnetized needle; the deviation of the latter is perceptibly greater the nearer the magnet is brought to it; it diminishes as the magnet is removed to a distance.

By experiments, which will be described and explained hereafter, it has been ascertained that the intensity of magnetic influence diminishes in the same ratio as that of all forces acting from a centre, viz. as the squares of the distances; so that, if the distance be increased two, three, four, $n$ times, the attractive force will be one-fourth, one-ninth, one-sixteenth, $\frac{1}{n^2}$ of what it is at the distance assumed as the unit.

## § 441.

As the nature of magnetism is as yet undiscovered, we are obliged to have recourse to hypothetical explanations when we account for the various magnetic phenomena: on this subject philosophers are of different opinions. Some suppose (as they do with regard to light and heat) that there exists an extremely subtle imponderable fluid, combined with the particles of those bodies which are susceptible of magnetic influence, perhaps indeed with the particles of all bodies. This fluid is further supposed to consist of two distinct parts, or rather of two fluids, distinguished as *north* or *positive* magnetism ( + M), and *south* or *negative* (—M); neither of which, however, is found singly combined with the particles of matter, but always both together. The particles of the same kind of magnetism display a tendency to repel each other, but the opposite kinds to attract. Now, if the relative proportions of these two fluids existing in any body be such that they mutually neutralize each other in the individual molecules composing it, no magnetism is displayed, and such a body would be said to be not magnetized. But if this condition of equilibrium be disturbed, or a separation be effected by any external cause whatever between these two fluids, then the magnetic state is induced and the magnetism is invariably *bipolar*, never *unipolar*. The attractive energy of each of the magnetic fluids may be further supposed to be accumulated in the respective poles. Every body that has acquired this state of polarity is in its turn capable of

disturbing the magnetic equilibrium of other similar
within certain limits, separating in them these two fluids o
forces, attracting that which is like and repelling that w
unlike itself. (Comp. § 272.) The derangement thus effe
the magnetic fluids is not sufficient to cause their passag
one particle of the body to another, still less from one bod
another. By assuming this hypothetical fluid to be thus co
with the molecules of substances, we can explain how a n
or any other body in a state of magnetic activity, may exc
same condition in others without any loss of its own pow
also why, when a magnet is broken, each portion is a co
magnet having two poles.

*Fig.* 131.

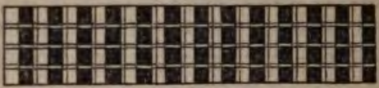


*Fig.* 131. may serve to give a visible representation
supposed distribution of the antagonist forces in the inter
magnet, the small squares representing the molecules of tl
net, each of which contains the two polar forces in their s
condition, divided so that the like are all turned in the s
rection, and the one force acts at one extremity of the
and the opposite force at the other end. (The antagonis
are expressed by the black and white chequers.) Hence
apparent why, if a magnet be broken across, each portion
a perfect magnet, and will have two poles. (See also the
*experiment*, § 437.)

This separation of the magnetic influences is not effect
equal readiness in all bodies. The more easily it is accom
the sooner do they again combine; or, in other words, tl
quickly any body becomes magnetized, the sooner also
lose the magnetic properties it had acquired. To accoun
fact, it is assumed that different substances offer a very
degree of resistance to the magnetic influence, which
separate the two species of magnetism they contain.
not assume that all those substances which have as yet
magnetic influence are therefore absolutely destitute of t
netic principle; it will be enough if we suppose that th
hitherto used have not been sufficiently powerful to o
their molecular resistance. According to another an
modern theory, deduced from observations on the pheno
electro-magnetism, or the mutual action of electricity ar
netism on each other, the latter has been regarded as m
electrical phenomenon. The reader will find the su

electro-magnetism treated of distinctly in the concluding sections of this work, to which he is referred for a full account of this theory.

### III. TERRESTRIAL MAGNETISM.

### § 442.

Since, by the law of magnetic polarity, unlike poles attract, it follows that, if a magnet be suspended freely between the dissimilar poles of a more powerful fixed magnet, the former will arrange itself, so that its north pole shall be opposite to the south pole of the latter, and its south pole opposite to the north pole of the fixed magnet; in such a manner, in fact, that the axis produced of the moveable magnet will pass through the poles of the fixed one.

> *Expt.* Suspend a small magnetized needle horizontally between the poles of a horse-shoe or bar-magnet. Whatever the position of the magnet with respect to the poles of the earth, the north pole of the needle will invariably be found to point towards the south pole of the magnet, and its south pole towards the magnet's north pole.

All magnets that have free motion in a horizontal plane in any part of our earth arrange themselves, so that one pole, called the north pole, points nearly towards the north pole of the world, and the opposite pole towards its south pole. — The inferences to be deduced from this fact will be considered presently; the fact itself is all that we assert now, viz. that a needle in any part of the earth invariably maintains a certain position as if it were placed between the two poles of a fixed magnet.

Now, if we conceive a vertical plane to be drawn through the axis of such a needle when in a state of rest, we have the *magnetic meridian* for the particular place where the needle is. There are but few points upon the earth's surface where the magnetic and geographical meridians coincide; consequently, the needle does not point due north. The angle which the former makes with the latter, at any place, is termed the *magnetic declination*, or the *variation of the needle* at that particular place. It is spoken of as either *east* or *west*, according as the needle points eastward or westward of the geographical meridian.

The magnetic needle is a highly important instrument for the natural philosopher; and to mankind in general it has proved of essential service in guiding the mariner safely over the trackless ocean. It enables the traveller in unknown regions to determine the azimuth of objects; it is used by the surveyor and by the miner; and lastly, it is employed by the mineralogist as a test of the presence of iron in minerals and ores. Of late it has been applied as a gauge of extreme delicacy of the intensity of certain electrical forces.

The simplest method of finding the magnetic meridian at any place is to suspend a needle by a piece of untwisted silk or cotton; but for many purposes it is more convenient to balance it upon a fine steel point, which is let into a small cap or cone just over the needle's centre of gravity. To diminish friction, the cap is frequently of agate.

*Fig.* 132.

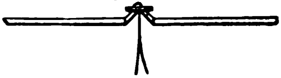


*Fig.* 132. presents a transverse section of a magnetic needle.

To render the variation of the needle susceptible of measurement, its point of motion is placed in the centre of a circle, which is differently divided, according to the purpose to which it is to be applied. In the *mariner's compass*, the circle traversed by the point of the needle is marked off into 32 *rhumbs* or *points*, whilst in the *azimuth compass* the same circle is divided into 360°. — If we wish to find the north and south points of the horizon accurately for any particular place by means of an azimuth compass, we ought to know the variation of the needle at that particular station, and make a proper correction for it. In some compasses this declination is expressed by a line; but, as we shall soon show, such a contrivance is of little use, as the declination is not only different at different places, but it varies from time to time at the same place. Again, for the purposes of geodesy, the compass is not to be implicitly relied on, as its accuracy may be affected by other causes, such as the proximity of strata of loadstone, basalt, &c.

The quantity of iron or other magnetic substances in minerals is found by observing how much they deflect the needle.

It is not known to whom we are indebted for the original invention of the compass. It has been asserted that the Chinese were acquainted with its use 1100 years B. C.; it was introduced into Europe in the 14th century.

§ 443.

Numerous observations made during several years have led to the conclusion, that there exist two lines on the surface of the earth on which the horizontal needle points to the true north; in other words, where the magnetic meridian coincides with the geographical. These *lines of no declination*, to which Professor August has given the designation of *agonic lines*, are two in umber: one, called the *American agone*, is in the western hemisphere; the other, or *Asiatic*, is in the eastern hemisphere. They xtend from south to north, but they do not coincide with the meridians; for they both, especially the Asiatic one, intersect the atter lines under different angles. It has further been ascertained, hat their position is by no means stable; for, after the lapse of onsiderable intervals of time, it is sensibly altered. The declination of the magnetic needle gradually increases on both sides of the agonic lines, and somewhere about midway between the wo it attains its maximum declination in both the northern and southern hemispheres. In those regions of the earth which lie west of the Asiatic agone towards the American, the declination is west of the north; in the other parts of the earth it is east. If those places which have an equal declination west or east be connected by lines, we have the *isogonic lines*, or *lines of equal declination*. Some of these form curves inclosing a space, whilst others branch off both north and south; most of them, however, are drawn around two points near to the north and south poles of our planet. These points, of which, until lately, it was thought there were two pairs, are called the *magnetic poles of the earth*, or, as Hansteen more correctly termed them, *magnetic points of convergence*.

Several philosophers have constructed maps, in which we are presented at a glance with the distribution and relative position of these lines on the earth's surface; the principal are those drawn by Hansteen, Barlow, Ermann, jun., Duperrey, Gauss, and Weber. Now if we inspect maps of this kind, constructed at different periods, we shall be able to see at once the changes which have taken place in the position of these lines. According to the most recent researches of Gauss, it is thought there is a greater and a lesser agone, the former embracing the globe like a meridian passing through the magnetic pole, and dividing the earth into two hemispheres, the eastern parts of N. and S. America being comprised in the western hemisphere, and New Holland, Arabia, Persia, and Russia in the eastern. The lesser agone forms an oval, and runs through Eastern Siberia, China, and the neighbouring sea.

Hence isogonic lines of western declination will be found in Europe, Africa, and the south-western parts of Asia; also in the whole of the Chinese empire, the Atlantic Ocean, and the Indian Sea. Similar lines of eastern declination are found in the greater portion of N. America, and in nearly the whole of S. America, the eastern half of Australia, India within and without the Ganges, the greater part of Siberia, and the whole of the Pacific Ocean. The mean *declination in* Europe is 17°; it increases towards the west (at Bonn it is 20°, at Edinburgh 26°, in Iceland 38°, in Greenland 50°); it decreases towards the east (at nigsberg it is 13°, and at Petersburg 6°).

On the position of the magnetic poles or converg points, more will be said in the observations, § 446.

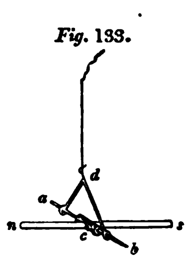
## § 444.

If a magnet, suspended horizontally, have free motion abou axis only in the vertical plane, then it follows by the law magnetic attraction, that if we place another magnet beneat its poles will be drawn downwards towards the contrary pol the lower magnet. Needles which are perfectly free about centre of gravity, but which have motion only in a vertical p are termed *dipping needles*.

If a dipping needle be placed over the axis of a magnet between its poles, then they will both exert an attractive repulsive influence on the needle; if their forces be exactly e which will happen if the needle be at an equal distance from extremity of the magnet, the needle being acted on by two forces in opposite directions, will obey the laws of gravity arrange itself in a perfectly horizontal position. But i needle be nearer to one of the poles of the magnet than t other, it will be more powerfully solicited by the former, and in precisely the proportion in which it is nearer to it. Th fluence of the more remote pole will be altogether annihil when the needle's centre of gravity is brought perpendicu over the other pole. One effect of this is, that the needle its horizontal position, and that pole begins to dip whi moved towards the contrary pole of the magnet, its depre constantly increasing, until at last the needle assumes a ve position. Next, if the dipping needle be placed so that the of its motion be at right angles to the axis of the magnet, it be perfectly horisontal when immediately above the mag point of indifference, *i. e.* midway between its extremities the needle be moved towards either of the poles of the ma it is obvious that it becomes subjected to the magnetic influ of only that one pole; it will, therefore, assume the ve position.

The above remarks may be readily verified, by plac dipping needle in the positions just named with respe a bar-magnet laid horizontally beneath it. — Pro Schmidt gives the following method of preparing a dip needle that may be used by such persons as do not p a more accurate instrument. — Thrust a magnetized kn

*Fig.* 133.

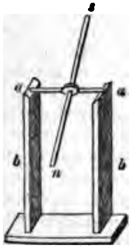


needle (*fig.* 133. *n s*) through a cork *c*; furnish the latter with an axis, consisting of two needles, *a* and *b*, at right angles to the magnetized needle. Let the direction of this axis go as nearly as possible through the centre of gravity of the whole mass. Suspend this instrument by a piece of wire, *a c d*, and fasten the whole to an untwisted silk or cotton thread. The needle *n s* is to be thrust so far into the cork that it may balance.

If an unmagnetized needle be suspended by its centre of gravity, and it be free to turn in a vertical plane (see *fig.* 133.), t will balance itself in a horizontal line. But if the needle be magnetized and placed with its plane of motion in the magnetic meridian, we shall find it has lost its horizontal position; that in the northern hemisphere its north pole and in the southern hemisphere its south pole become depressed; and that it assumes one certain position, to which it invariably returns on being displaced. If the needle's plane of motion be at right angles to the magnetic meridian, the needle becomes vertical.

*Second Expt.* This phenomenon may be most simply illustrated in the following manner: — Drill a hole in the middle of a piece of watch-spring, pass a needle through the hole, so that the watch-spring may be turned round in a vertical plane, and, come into a horizontal position, when in a state of rest. — Now magnetize the needle and place it a second time upon its axis. (§ 454.) — It will be at once seen that its equilibrium is disturbed, and that it takes the slanting position of which we have spoken above.

*Fig.* 134.



A needle may be fitted up in the same manner as we have already described in the first experiment; but instead of suspending it by a wire fork, it will be better to lay the ends of its axis on the edges of the uprights *b*.

When a magnet has been mounted so as to have perfect freedom of motion about its centre of gravity, the angle it makes at any point on the earth's surface with the horizon is called the *angle of the needle's dip* at that place. As has been already said, at all places in the northern hemisphere the north pole is depressed, and in the southern hemisphere the south [illegible] instruments intended accurately to measure the magnitude [illegible] angle are termed *dipping needles*, and are very [illegible] on account of the difficulty found in practically constructing them. To estimate the magnitude of the angle made by the needle, the apparatus has a vertical circle of brass graduated [illegible]

## § 445.

[illegible] the needle, as well as its variation, differs at different places. There is an irregular curve in the neighbourhood [illegible] equator, where a needle balances itself [illegible] horizontally. This curve, to which Professor August has given the name of the *aclinic line* (it is also sometimes called the magnetic equator) does not coincide with the equator, but cuts the latter [illegible] nearly opposite points in such a manner, that the [illegible] situated in the western hemisphere runs south [illegible] equator of the earth, and the portion contained [illegible] hemisphere runs northward of the same line. [illegible] northwards, the dip of the north pole of the needle increases [illegible] in the same proportion as the latitude of the [illegible] increase in the dip of the south pole obtains in the [illegible] hemisphere. If we connect those places in the two [illegible] the dip is equal, we obtain *lines of equal dip*, [illegible] the globe, running nearly parallel [illegible] equator. It is worthy of remark, that a [illegible] is found to subsist in the position of these [illegible] the isothermal lines. (§ 425.) This seems to [illegible] the earth's magnetic condition is in some way connected [illegible] heat.

[illegible] equator is not a circle, but rather a curve [illegible] with many deflections, especially in the [illegible] the nodal points, or points of intersection. [illegible] these last named points, and indeed that of [illegible] is extremely variable; and as far as observation [illegible] shown, it appears to move progressively from [illegible] One of these nodal points is at present near the [illegible] St Thomas in 8° E. lon.; and the other in the [illegible] about 142° E. lon. The greatest declination [illegible] magnetic equator from the equinoctial line amounts to about [illegible] in the northern hemisphere, and is attained in [illegible] or thereabouts; and its greatest southern declination [illegible] the western hemisphere, is near the Bay of Bahia [illegible] W. lon. — The dip in Europe ranges from 60° [illegible] over the magnetic pole of the earth it must amount [illegible] In the year 1836, in the northern hemisphere, pr[illegible] ceeding from the magnetic equator northwards, the dip was 54° 49′ at Pekin, 61° 42′ at Rome, 68° 32′ at Brussels, and 71° at Petersburg; in the southern hemisphere it was 14° 50′ at St. Helena, and 13° 30′ at Rio Janeiro.

A. von Humboldt gave the first impulse to the construction of charts, which might show the dip of the needle in much the same manner as the magnetic maps we have just described exhibited its declination: in the execution of his plan he received important assistance from Hansteen, Ermann, and Duperrey.

## § 446.

The phenomena of the declination and dip of magnetic needles at the earth's surface are seen to coincide exactly with the effects produced by a bar-magnet on such needles; hence we are compelled to infer, that our planet is itself a bipolar magnet, whose poles do not exactly coincide with the poles of the earth's axis, but which lie somewhere near the latter points; that, agreeably to the fundamental law of magnetic influence, they attract only unlike poles; but as the north pole of a magnet dips in the northern hemisphere, and the south pole in the southern hemisphere, it follows, that the northern hemisphere has a south polar magnetism, and the southern hemisphere a north polar magnetism.

For this reason some philosophers, the French especially, have called that pole of the needle which points to the north, the south pole, and the end which points to the south, the north pole.

By the magnetic poles of the earth, of which we have spoken in this and the preceding paragraphs, the reader is not to understand fixed points, but regions, in one of which the south polar magnetism is concentrated, and in the other the north polar magnetism, the fluid itself being supposed to be distributed over the whole of the earth. Hansteen was of opinion that there were two of these points in the northern hemisphere, and, reasoning from analogy, that there were two also in the southern hemisphere, these magnetic poles being near to the poles of the earth's axis. One of these he believed to be situated in North America, a little west of Hudson's Bay, in 80° N. lat. and 96° W. lon.; the other in North Asia, in 81° N. lat. and 116° E. lon.; the southern magnetic poles he placed a few degrees farther from the south pole. Gauss's more recent observations have, however, led to the belief, that there exists but *one* such pole in each hemisphere. Sir James (then commander) Ross *found one of these* during his arctic expedition of 1829

Ross, in the year 1831, to be in the vicinity of Hudson's Bay, in 70° 5′ 17″ N. lat., and 114° 55′ 18″ W. lon., when the dipping needle was within 1 minute of being vertical, a difference which may fairly be attributed to an error in the observation. The actual existence of the magnetic pole in that spot was further proved by noticing that the variation needle, when carried round, always pointed to that spot, and when in that station followed the course of the sun in his circuit around the horizon. Gauss theoretically fixes the position of the magnetic pole in the southern hemisphere in [illegible] S. lat., and 152° 30′ E. lon.

The inductive effects of the earth also prove its magnetic state, inasmuch as they bear a striking analogy to the induction of magnetism by ordinary magnets in bodies susceptible of this influence (§ 486.) These magnetic effects of the earth are attributed to the operation of *terrestrial magnetism.*

*Exp.* To verify the inductive power of terrestrial magnetism, procure a bar of soft iron from 2 to 3 feet long; a bundle of iron wire, insulated by a wash of sealing-wax dissolved in naphtha, or spirits of wine, will do still better; a common variation needle moving freely on a point will then show the various magnetic states of the iron bar caused by shifting its position with regard to the earth.

Hold the bar in a horizontal position, and at right angles to the direction of the needle, so that one of its ends shall be over the middle of the latter; the needle will be unaffected, for the bar will be in a state of magnetic indifference. Now shift the position of the bar, inclining it gradually in the direction of the magnetic meridian, and it becomes magnetized, and acquires two distinct poles, its maximum intensity being attained when held parallel to the dipping needle at the place of observation. Bring the lower end near to the north pole of a variation needle, and its north polarity will be shown by its repelling the needle; bring the upper end to the south pole of the needle, and by repellin it will become evident that this end of the bar is a sou pole. Reverse the position of the bar, and you at the san time reverse its poles.

These phenomena are generally spoken of as the results magnetism by position.

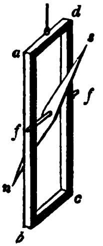
The experiments performed by Barlow with large ir balls called terrellas, are extremely instructive. These bal by the inductive influence of the terrestial magnetism, a quired a magnetic condition answering to that of the ear itself. On one of these globes, 13 inches in diameter, traced the existence of a magnetic axis and a magne equator. The former had the same position as a dipp needle, and when small and delicate magnetized needles were placed on the latter in their normal position, they suffered no disturbance; whereas, in any other part of the sphere they exhibited both a declination and a dip.

### § 447.

The position of the poles of a needle and its dip, varied as we l them both to be in different parts of the world, must be arded as the result of the attraction exerted by the north and th magnetism of the earth. This force is put forth in two ections upon magnets, viz. horizontally, by which the position a needle is determined, and vertically, by which its dip is ulated. If a magnet be perfectly mobile, both horizontally l vertically, it will obey both these forces and take up a ition which expresses the *mean force of terrestrial magnetism*. ery dipping needle that has motion in the magnetic meridian es this line; and if we conceive a plane to intersect the axis of h a needle at right angles, we shall have its magnetic equator. dipping needle be so placed, that its plane of motion stands right angles to the magnetic meridian, or if its axis lie in the er, then the needle will not be acted on by that part of the estrial magnetism which is exerted in the plane of the horizon, only by that which acts in the vertical plane; it will conuently assume an upright position.

The most simple form of magnetic apparatus in which a needle can have this two-fold free motion, is that represented in *fig.* 133., and described already in the *first experiment*, § 344. This construction will not, however, give a very accurate instrument. Care must be taken to fix the needle *n s* in the cork, and to balance it as exactly as possible before it is magnetized; and in magnetizing it, its position must not be disturbed. *Fig.* 135. represents a more accurate kind of instrument. *n s* is a magnetized needle; in the centre of gravity it has an axis placed at right angles to itself, and about which the needle turns with extreme facility on the ends of two screws *f f*. These screws go through the parallel uprights of a light brass frame *a b c d*, that has a small hook at top, in which an untwisted silk thread may be fastened, and the whole apparatus can be hung up under a bell-glass.

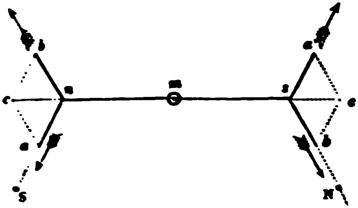
*Fig.* 135.



The following observations will prove that the inclination of such a needle gives the direction in which it is acted upon by the resultant of the terrestrial magnetic force

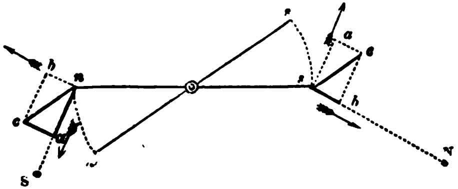
Let S and N be the two magnetic poles of the earth, and let *n s* be a magnet moving freely, both horizontally and vertically, about its centre of gravity *m*. The

*Fig.* 136.



attractive and repulsive influence of the poles N and S, in the horizontal direction, impart to the needle its position *n s*, with regard to the poles, such that its axis lies in a line joining N and S: any further approach towards the more powerful pole will be prevented by the suspension of the needle on the fixed point *m*. The needle's dip will be regulated by that portion of the magnetic influence which is exerted in the vertical plane. We will assume first, that the needle is situated just midway between the two poles N and S, and, consequently, every part of it will be equally solicited; and the point *n*, for instance, will be drawn in the direction *n* S, by the pole S, just as strongly as the point *s* is repelled in the direction *s a*. The line *n a*, which expresses the magnitude of this attraction, must therefore be equal to *s a*, and as the distance of the earth's poles from these points is so great the two lines *n a* and *s a* may be regarded as parallel. The other magnetic pole N acts in like manner, attracting *s* as powerfully in the direction *s* N, as it repels *n* in the direction *n b*; whence also *s b* is equal to *n b*, and these two lines are likewise parallel. Now, by the parallelogram of forces (§ 23.), *n c* is the resultant for the point *n*, and *s c* for the point *s*; but they are both equal, and in exactly opposite directions, whence the needle will be held in a horizontal position. Next, let us take the case when the needle *n s* is nearer one of the earth's magnetic poles than it is to the other, and let us suppose it to be nearer to S; then the point *n* will be as strongly solicited by the pole S, as *s* is repelled by it, so *n a* will be equal to *s a*; the pole N will attract *s* as powerfully as it repels *n*, whence *s b* = *n b*. But the attractive force of N is less than that of S; for N is more remote than S, *n b* and *s* will therefore be less than *n a* and *s a*. The resultants

*Fig.* 137.

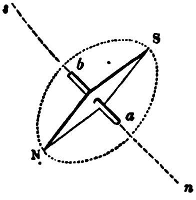


and *s c* will in this case be equal and parallel, but not exactly opposite to each other: they will therefore cause the needle to turn about its fixed point, and it will only come to rest in the direction *n′ s′*, parallel to the resultants *c n* and *c s*; this therefore, will be the dip of the needle.

## § 448.

It is important for many purposes to have magnetic needles on which the earth cannot exert any directing influence: needles of this kind are called *astatic needles*. A magnet moving freely can be rendered independent of terrestrial magnetism, by giving its axis of rotation precisely the inclination which a dipping needle placed in the magnetic meridian would have taken. Thus, if *n s*, (*fig.* 138.) were the dip of such a needle, all that would be required would be to place the axis *a b* of the needle N S in the direction *n s*, and it will be immediately converted into an astatic needle. The earth acts in the direction of this fixed axis upon the needle, whose movements are performed in the plane of the magnetic equator; it will, therefore, rest in any position whatever in this plane.

*Fig.* 138.



Another, and for many purposes a more useful, sort of astatic eedle may be thus constructed. Two needles (*fig.* 139.) whose agnetic powers are as nearly equal as possible, are fastened on a ommon axis *a b*, which is suspended by an untwisted silk thread *c*; the needles are parallel to one another, and the north and outh poles of the upper needle are over the south and north oles of the lower one. By means of this arrangement, neither f them *can assume* any particular position with respect to the

the intensity of the force of gravity is indirectly as the squares of the times of the pendulum's oscillations.

Again, as the number n and N of oscillations performed in equal times is inversely as the length of an oscillation, it follows that

$$I : I' = n^2 : N^2;$$

the squares of the number of vibrations performed in a given time by the same pendulum are as the intensity of the force of gravity.

Now let this be applied to magnetized needles, and for the force of gravity substitute the magnetic intensities m and M, then

$$m : M = \frac{1}{t^2} : \frac{1}{T^2}$$

$$m : M = n^2 : N^2;$$

the intensity of terrestrial magnetism at different places on the earth's surface, when applied to magnetic needles, is inversely as the squares of the times of their oscillations, and directly as the number of oscillations when the times are equal.

Suppose that at the station A the needle makes a certain [illegible] oscillations in [illegible] seconds, while at B it would [illegible] same number in [illegible] seconds; or, expressing it in [illegible] the needle makes [illegible] oscillations at A in the [illegible] at B: then the intensities of [illegible] m and M at the two places will be

[illegible]

[illegible] intensity M, at station B, is nearly double th[illegible] station A.

This mode of experimenting is applicable to both the [illegible] dipping-needle. It can be employed [illegible] to the former, both because it is more [illegible], and because the duration of its osc[illegible] as fewer obstacles impede its motion. [illegible]needle we can measure only [illegible] magnetism which acts horizonta[illegible] needle only that which is exerted ve[illegible] by means of the parallelogram of for[illegible] 'ever, we can readily prove, that the intensity ther of these modes is proportional to the t terrestrial magnetism. otal

Let *n s*, *fig*. 140., be the directing force of the earth's magnetism, as shown by a dipping needle in the magnetic meridian of a place (§ 447.), and let $n\,a = P$ represent this force, which may be resolved into $n\,b = H$, in the direction of the horizon, and $n\,c = V$ acting in the vertical plane. Now if $a =$ the angle of the dip (§ 444.), it is evident that $P = \frac{H}{\cos.\,a} = \frac{V}{\sin.\,a}$; *i e.* the total effect of the magnetic influence exerted by the earth at any particular place is found by dividing the horizontal intensity by the cosine, or the vertical intensity by he angle of the needle's dip.

/ing the oscillations made by a dipping-needle, ısure the dip or inclination of the needle at any lace. First, place the needle in the plane of the eridian, then in a plane vertical to the former; vibrate in both these positions, and count the ›scillations made in equal times in each position, be found that the number N performed in the ; that made in the second *n*. In the plane of the ıeridian they obey the entire magnetic influence he vertical plane the needle is acted on only by V of the force which is exerted vertically. We ly found $P = \frac{V}{\sin\,a}$; whence sin. $a = \frac{V}{P} = \frac{n^2}{N^2}$.

'esults found by observing the oscillations which edle makes at different places, will give us accu- for the intensity of the earth's magnetism, if the ıate free magnetism undergo no change, but not In the small needles which were formerly em- s rarely happened to be the case, as they are af- ariations in the heat, and still more sensibly by ɜ of masses of iron and other similar bodies. To ıst these sources of error, Gauss made use of bars ı 1 to 4 feet in length, and weighing from 1lb. to which he gave the name of *magnetometers.* The .hese masses, in addition to the other precautions :ured these bars from the operation of external in- Γhis simple but ingenious apparatus surpasses all the instruments previously contrived: for it is capable of indicating the minutest changes that transpire in the intensity of the earth's magnetism by proportional variations of the magnetometer from its normal position, which changes can be measured to an angle of one second; hence all the magnitudes which it is desired to investigate with regard to the intensity of the terrestrial magnetism, may be found with the most rigid precision.

The oscillation-experiments with common variation needles can be advantageously applied only when we are warranted in assuming that the intensities of the needles themselves undergo no change: with this proviso they may be used for comparing the different powers of magnets, or in estimating the minute magnetic influence of other bodies, as will be shown presently.

§ 452.

Observations made during many years, and the accumulated experience of philosophers have shown, that there subsist both regular and irregular variations at the same place in the earth's magnetic powers, as indicated by changes in the declination and dip of the needle, and in the magnetic intensity.

The regular variations are such as follow a certain law, and which, when we are acquainted with that law, can be calculated beforehand. Professor [illegible] distinguishes them into [illegible] such as become evident only after the lapse of lengthened periods, and periodic, which oscillate in a manner within certain short periods of time.

Of the secular variations the declination is that which has been longest observed, and is most accurately known: our information with respect to the dip and intensity rests on fewer data, and is of more recent origin.

Variations were first observed to take place in the declination of the needle in the 16th century, but it was not till the 17th that anything was accurately known as to the rate of these changes. About the year 1600, the needle in Europe pointed to the east of the north; in 1663 it pointed due north; from which time its deviation westwards gradually increased to the close of the preceding century. For a short period after the commencement of the present century the needle was stationary, but for the last 20 years its declination has certainly decreased, and, in all probability, it will continue to do so until it again becomes due north, then the declination will increase towards the east, and when the needle has attained a maximum it will again return. The needle began to retrograde at London in 1819; at Paris, and throughout the greater part of Germany, in 1814. At Berlin, the declination in 1840 was 16° 42′, and the annual decrease is about 3° 8′.

The only observations made on the variations in the dip of the needle, are both few and unsatisfactory; all that is known with certainty is, that at present the dip in Europe is decreasing. In the year 1780, the annual decrease in Europe was from 5′ to 6′; in 1830 it was but 3′; whence it appears that the dip has nearly attained its maximum. According to the observations made in 1840, the dip at Berlin was 67° 53′, with an annual decrease of 3·5′.

Our knowledge of the variations in the magnetic intensity is still more defective, for it is but recently that this subject has been investigated. Hansteen believes, on theoretical grounds, that we may assume the intensity also to be decreasing, and that this decrement in Europe is annually 0·003695.

The diurnal and annual variations of the declination-needle consist in an oscillation eastward and westward of its mean position. The magnitude of the diurnal variation differs according to the situation of the place, and the time of day and year. It appears to be very intimately connected with the generation of heat by the sun. In the middle of Germany, in winter, it is about 8′, and in summer about 16′. In the more southern regions, which lie nearer to the magnetic equator, the daily oscillations become less, and at the equator itself they vanish entirely. Recent observations have placed it beyond all doubt, that storms materially affect these periodic changes in the variation needle. With a clear sky and an easterly or north wind, the fluctuations have been found to be greater than when the weather is cloudy, and a south or west wind prevails. In this case, also, the results seem to be affected by solar influence.

From a comparison of the observations made on the declination of the needle at different places, the following results have been arrived at:—

1.) The time of the greatest declination ranges between 6 and 9 A.M., happening earlier in summer than in winter.

2.) The time of the greatest declination westward is about 15′ past 1 P.M.; but this depends on the season of the year.

3.) The oscillations in summer are greater than in winter. According to Kreil's observations made at Prague, 1839-40, in summer the arcs moved through are three times as great as in winter. The greatest oscillation noticed in any one day, by Gauss, was 20·1′.

4.) The *oscillation* during the night is inconsiderable.

[illegible] these irregular disturbances in a direction opp that in which the magnetic lines run.

It has been observed already (§ 432.) that rathe than ten years ago the indefatigable A. v. Humbol the founder of the Magnetic Association, which ha extended itself throughout the greater part of the The object of this association is to investigate the ca the various magnetic changes in the earth's magnetism, if possible, to ascertain precisely the influence it exerts. [illegible] this purpose simultaneous observations are made with G magnetometers at various stations at and beneath the e surface. The communications addressed to this society shown, that not only the greater variations in the e magnetic influence, but also the most minute, nay, even irregular disturbances have been perceived simultaneously points far asunder. Although the changes observed did universally coincide in degree, yet their occurrence at t same time proves beyond question that they are connecte and establishes the fact of a remarkable coincidence in the phenomena throughout the world.

### § 451.

One question remains to be answered. — What notion shall we [illegible] the earth's magnetism, which shall enable us to explain [illegible] both the constant and varying magnetic phenomena [illegible] themselves to our notice? Until lately philosophers [illegible] ascribing to the earth a sort of independent mag [illegible] have further assumed that this force had its seat [illegible] of our planet. Of these theories Hansteen's is both [illegible] and the best supported. He conceived that [illegible] phenomena were owing to a magnetic power resident [illegible] of the earth, and that its influence was especially [illegible] at four points. He further supposed that [illegible] this force with equal intensity in two opposite [illegible] axes, the poles of these axes being at a considerable [illegible] the earth's surface. To account for the variations [illegible] the needle's declination and dip and in the mag [illegible] attributed to these axes, and so, of course, t [illegible] progressive motion, in consequence of which th [illegible] poles of the northern hemisphere point more a [illegible] the east, and those in the southern hemisphe [illegible] the west. If these assumptions are admitted, th [illegible] adequately explain all that was formerly known wi [illegible] phenomena of terrestrial magnetism as w [illegible] irregular variations to which it is subject; yet,

it must be confessed that the researches of modern
wn many bodies to possess magnetic properties which
ly believed to have any; that for many important
f which will be adduced presently, it appears to
l whether the earth has any magnetic axes; and
rior of the earth is the seat of magnetic influence
ore so. One of the most weighty objections to
be found in the now well ascertained diurnal and
s in the magnetic declination and dip, which the
he Magnetic Association have proved to coincide
er remarkably in different parts of the world.
added to the fact that the northern point of mag-
e very nearly agrees with the point of the earth's
icial heat, and the evident influence of that agent
na of the earth's magnetism and on magnets in
52. and 462.), have led to the construction of
which seems to afford a more natural explanation
l by Hansteen's hypothesis. The main features of
that the earth's crust, and not its interior, is the
m; that in the northern hemisphere a north, and
a south magnetism predominates — the intensity
reasing from the equator towards the pole, but
the two hemispheres. The resultant of this in-
int on the earth's surface is caused by the separ-
magnetic fluids in the component particles of the
th to which this supposed separation extends is
cted with the mean heat of the earth's crust, if it
onsequent upon it. According to this theory,
have no actual existence; but are merely mathe-
ich represent to our minds the places where the
single forces is combined. The impartation of
turally be subject, through the excitation of heat
nstant variations, which will return as period-
n of the sun itself. The changes in the earth's
are accordingly held to be dependent on the
s surface; the diurnal variations being caused by
and decrease in the temperature, and the annual
e periodical fluctuations above and below the
perature. The position and form of the magnetic
cially the whole system of the isoclinic curves, is
e distribution of heat in the two hemispheres.
re and degree of the needle's declination and the
sogonic lines are explicable if attributed to the
.

dence has yet been obtained to show whether
fined to our earth and the substances it contains,
agent is common to it with the other heavenly

bodies. Some philosophers are of opinion that they have detected traces of its operations in them; and certainly the points of resemblance, as to form, motion, the position of their axes, &c. among the planets are so numerous, that we are disposed to think that magnetic influence extends even far beyond the limits of our solar system.

## [illegible] THE ARTIFICIAL PRODUCTION OF MAGNETISM, THE MEANS OF [illegible] AND INCREASING IT, AND THE DIFFERENT METHODS BY WHICH TO [illegible] OR DESTROY IT.

### § 452.

The intensity of the magnetism of which any magnetizable body is susceptible, depends on the coercive power (§ 441.) of the substance composing it. The less this force or the resistance which a body is able to offer to the separation of the magnetic fluids, the more easily is it magnetized — the more readily too does it lose the whole or a part of the magnetism it had acquired. The greater the coercive power, or the more powerful the resistance offered, the more difficult is it to magnetize the body, and the longer does it retain the magnetism imparted to it, i. e. the longer does it hold the two fluids asunder. In non-magnetizable bodies, this resistance altogether prevents their receiving magnetism; in such as are magnetizable, on the contrary, it is the cause which in a certain degree maintains the separate condition of the two [illegible] According to Barlow's experiments, pure soft iron [illegible] the least resistance to magnetization, next soft steel, the [illegible] steel, and lastly cast iron.

Recent observations have shown, that the resistance of m [illegible] is greatly modified by heat: that by raising th [illegible] temperature this resistance is lessened: so that for every body [illegible] there is some particular temperature, at which it [illegible] On being heated to this point the body b [illegible] insensible to the most powerful magnetic influence, and consequently incapable of being magnetized. The limit at whic [illegible] susceptible of magnetic influence, is [illegible] heat of about [illegible] Fahr. When very near this tem [illegible] they still retain a coercive force, which enables them t [illegible] the most powerful magnetism; but if heated beyond thi [illegible] they become white, they both lose all sensibility to magnetic influence. Thus heat seems to exert a controlling [illegible] over a body's capability for yielding to magnetic influence. [illegible] does not appear that heat ever induces magnetism; i [illegible] merely a modifying cause, and the different degrees of magnetic susceptibility depend on the cohesive force of the substance as affected by heat.

There is also a limit to the quantity of magnetism, that a body can receive and retain. This limit is called the *point of magnetic saturation*, and from what has been just advanced, it is evidently dependent on the coercive power of the substance. Whether any particular body has or has not attained this point, depends on the intensity of the magnetic influence to which it is subjected, and also on the length of time it has been in operation, for if the force be too feeble, and the time too short, the point of saturation will not be reached. A body may even be *overcharged*, *i. e.* so extreme a tension of its magnetic forces may be induced, as can be maintained only whilst the body is acted upon by the magnetising body; and on the removal of the latter, the coercive force more or less slowly regains a portion of its power. The polar forces are maintained in an effective state by connecting the poles of the magnet with some other body, such as soft iron, of lower coercive power than itself.

Hence, whenever we wish to excite a mere temporary magnetism, we employ pure soft iron; but when we desire the magnetism to be permanent, we use hardened steel. All artificial magnets are made of hardened steel, though nickel and cobalt may also be rendered permanently magnetic.

The steel best suited for artificial magnets is of a fine grain, of uniform structure throughout, and free from flaws. A principal requisite is, that it should possess a proper degree of hardness, and that it should be equally hardened throughout the entire mass; for, if too hard, it is extremely difficult to impart to it any magnetic virtue; and if too soft, it readily loses it when given. It has been found most advantageous to make the steel in the first instance brittle, like glass, and then to heat it a second time, till it becomes of a straw, or violet colour.

The capacity and tenacity of artificial magnets are also affected by their form and dimensions. It has been ascertained that the breadth of a bar magnet should be about one-twentieth of its length, and its thickness from one-fourth to one-third of its breadth. In a horse-shoe magnet, the space between the two poles ought not to be greater than the thickness of the bar of which the magnet consists. Lastly; it is necessary that both bar and horse-shoe magnets be well polished, and that their faces be as level as possible.

The poles of a magnet, when not in use, should be in contact with a *keeper*, especially the poles of a horse-shoe magnet. The keeper tends to maintain, and even exalt, the power of the magnet, whose poles are thus employed in producing the opposite magnetism in the respective ends of the keeper, which should be made of the purest and softest iron. The keeper should be in absolute contact with the two poles of the horse-shoe magnet, or with the opposite poles of two bar magnets, which should be placed in a line.

### § 453.

There are various methods of magnetization, but the most effectual are, of course, such as most quickly and completely overcome the resistance. Those known as yet are — 1.) By immediate contact with magnets either natural or artificial; 2.) by distribution, or by being brought into the vicinity of such magnets; 3.) by various mechanical manipulations; 4.) by the solar rays; 5.) by electricity.

### § 454.

The most common and the readiest method of magnetization is that first named. It admits of three modifications; that is to say, the bar to be magnetized may have the magnetic virtue imparted to it by *mere contact* with another magnet, or by *drawing the pole* of the latter along its surface, or by being held in contact with the pole of a magnet, and then being struck with a piece of soft iron.

By mere contact the end of the steel which touches the pole of the magnet acquires a dissimilar magnetism to that of the pole with which it is in contact, and its other end acquires a magnetism similar to that of the pole. The magnetic equilibrium of the body is disturbed by the pole at the point of contact, the dissimilar magnetism is attracted, and the similar repelled; and if the body's mass is not too large, this effect is propagated throughout the whole of the body.

*First Expt.* Touch one end of a sewing needle with the north pole of a magnet; on separating them you will find that the end which was in contact has become a south pole, and the other a north pole.

*Second Expt.* Touch a needle in the middle with the north pole of a magnet, its middle will be a south pole, and its extremities will be north poles. We have thus obtained a magnet with three poles, and in a very simple manner an astatic needle of more or less accuracy. (§ 448.)

*Third Expt.* On a clear polished steel surface draw any figure whatever with the pole of a powerful magnet, then sprinkle iron filings upon the plate, and they will remain suspended wherever the magnet has passed.

The magnetism thus imparted is, however, less powerful than that communicated by drawing the pole of a magnet several times along the bar which is to be magnetized. The touch is aid to be *single* or *double*, according as it is effected with one pole, r with the opposite poles of two magnets at once.

The process may be explained in accordance with the theory advanced in § 441., if we suppose the pole of the magnet which is drawn along the bar of steel to separate the polar forces in every particle of the steel in such a manner, that the opposite magnetism to its own is excited in the direction in which it is moved. This motion will correspond exactly to that which may be observed in iron filings, strewed on a smooth plate of glass, when a magnet is passed along the under-surface of the glass. At the points above the poles, the particles of iron are seen to stand upright, the ends next the pole have an opposite magnetism to it, the ends more remote a similar magnetism. As the pole of the magnet is moved forward, the particles of iron fall down so as to turn their dissimilar poles to the pole of the receding magnet.

The *single touch* is performed by placing one pole of a magnet in the middle of the steel bar, and then drawing it evenly along to the end of the bar; when it has reached the end, the magnet is returned again through the air to the middle of the bar, and the stroke is repeated in the same direction. When this has been done several times, place the other pole in the middle of the bar, and proceed as before. Two magnets may be placed together with their dissimilar poles in the middle of the steel bar, and then be moved in opposite directions towards its two extremities. Each end of the bar which has been thus treated becomes a pole opposite to that with which it has been stroked; *i. e.* the end which has been operated on with the north pole of the magnet becomes a south pole, and *vice versa*. The bar will be impregnated more powerfully if its ends are laid on the poles of two magnets so that contrary poles of the bar and of the magnets may be in contact. This is the mode most generally adopted in forming an artificial magnet to be used as a needle.

To magnetize a bar of steel by means of the *double touch*, two bar or horse-shoe magnets are fastened together, so that their dissimilar poles may be about ¼ of an inch asunder. This will be done most conveniently by inserting a small wedge of wood or paper between them, and tying the magnets together. The apparatus thus arranged is placed vertically on the middle of the steel bar, and is then drawn towards the end of it, care being taken that neither of the poles glides over the end of the bar; the magnet is then returned towards the other end, and so on. Instead of thus combining two bar magnets, a horse-shoe magnet may be used if its poles lie pretty near together. In either case the process is concluded by drawing the magnet only half way along the bar, and then sliding the magnets off sideways. The poles will be dissimilar to those of the magnet. It will be found advantageous to lay the ends of the bar on the poles of two magnets in the same way as when the single touch is used. The *cross touch* is merely a modification of this experiment, by which the operator is enabled to magnetize two bars of steel at once. This can, however, be better performed otherwise, as we shall explain presently.

A bar in the form of a horse-shoe is very readily magnetized, as its two ends are easily connected by means of a keeper, whilst the magnet is being drawn across it, and thus the point of saturation is sooner arrived at. The methods already described can be applied to the magnetizing of bars in the form of a horse-shoe; but the following mode, invented by Hoffer, is superior on account both of its simplicity and effectiveness.

*Fig.* 141 *a.*

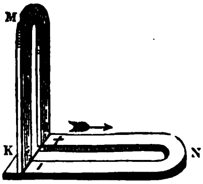
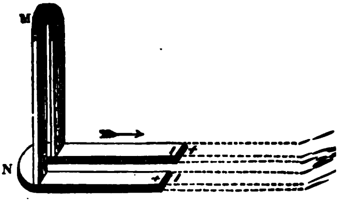


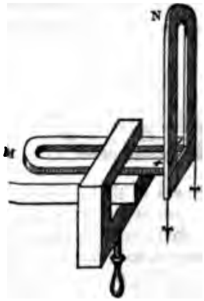
*Fig.* 141 *b.*



If there be only one horse-shoe N to magnetize (*fig.* 141 *a* it will be best to set it flat on a table, and laying against ends a piece of iron as a keeper K, place a horse-sh magnet M, whose legs are at exactly the same distan asunder as those of the bar to be magnetized, with its pol perpendicular to the keeper; and holding it still in this pos tion, draw it along towards the bent part of the horse-sho on reaching which the magnet is to be brought back to it original place on the keeper without touching the bar as i returns. It is then to be drawn as before along towards the curved part of the bar. After this has been performed from four to six times, the steel will generally be found to have acquired a pretty strong magnetic power; the polarity of each leg will be similar to that of the leg of the magnet which stands on it. The touch may be performed in exactly the opposite direction, the magnet being drawn (M, *fig.* 141 *b.*) from the curved part N of the horse-shoe towards its extremities, and in this case the keeper will not be required.

Each leg too will acquire an opposite magnetism to that of the pole which rests on it. If it is wished to magnetize two equal horse-shoes at once, they are placed, as shown in *fig.* 141 *b.*, with their ends close together, so as to form a sort of ellipse, and the magnet M is drawn from end to end. — If the magnet be large and heavy, say 10lbs or more in weight, these manipulations would be difficult, or altogether impracticable. The arrangement made by Von Vest may, therefore, be adopted with convenience. The magnet M (*fig.* 142.) is laid on a table, so that its poles project over the edge; it is secured in its position, either by means of clamps, or by putting a heavy weight on the bent part of it. Then hold the horse-shoe N you desire to magnetize in a vertical position against the magnet, a keeper being previously held to the ends of the horse-shoe. Be careful that the end intended to be made the north pole of the horse-shoe be in contact with the north pole of the fixed magnet. Now press the horse-shoe down in the direction indicated by the arrows in the diagram till the curved part touches the poles of the magnet; then invert the shoe, so that the keeper comes uppermost; place the similar poles together, and move the horse-shoe upwards till the curved part again touches the poles of the magnet. Once more reverse the position of the plate, so as to place it just as when the operation began. The process may be repeated so long as is requisite, care being taken to keep the similar poles together. The touch may in this case be reversed, and the keeper may be dispensed with, only minding to put that leg of the plate which is marked for a north pole against the south pole of the magnet. With regard to the relative efficiency of these different modes of touch, Von Vest's experience goes to prove, that it depends on the individual peculiarity of the steel itself, as he found that some plates were more powerfully magnetized by the first method, and others by the second or third. Von Mohr's method is precisely the same as Hoffer's second, excepting that before the magnet is detached from the horse-shoe it is used to impregnate, a keeper is placed against each of them.

*Fig.* 142.



This method of touch may also be employed for magnetizing two or more bars at once. For this purpose lay for which reason horse-shoe magnets are superior to bar-magnets of similar dimensions and character. It has further been ascertained that small magnets have a much greater relative force than large ones.

When magnetism is excited in a piece of steel in the ordinary mode by friction with a magnet, it would seem that its inductive power is able to overcome the coercive power of the steel, only to a certain depth below the surface; hence we see why small pieces of steel, especially if not very hard, are able to carry greater relative weights than large magnets. Sir Isaac Newton wore in a ring a magnet weighing only 3 grains, which would lift 760 grains, *i. e.* 250 times its own weight.

Bar-magnets are seldom found capable of carrying more than their own weight, but horse-shoe magnets of similar steel will bear considerably more. Small ones of from ½ an ounce to 1 ounce in weight will carry from 30 to 40 times their own weight, while such as weigh from 1 to 2 lbs. will rarely carry more than from 10 to 15 times their weight. The author found a 1 lb. horse-shoe magnet that he impregnated by means of the feeder, able to bear 26½ times its own weight; and Fischer having adopted the like mode of magnetizing the steel, which he also carefully heated, has made magnets of from 1 to 3 lbs. weight that would carry 30 times, and others of from 4 to 6 lbs. weight that would carry 20 times their own weight. Both the form and material of the feeder seem to influence its capacity for conveying the magnetic influence. It should be of the purest iron, and perfectly free from carbon; its face should be very smooth, that the contact with the pole of the magnet may be as complete as possible; and its form should be rounded, so as to resemble a cylinder. Until lately the construction of compound magnets of extraordinary power has been rather matter of curiosity and dilettantism than of any practical utility; but since the invention of the electro-magnetic machines, in 1833, a necessity has arisen for the construction of powerful magnets, and hence it has become of importance to ascertain the most certain and expeditious methods of imparting magnetic virtue.

M. Häcker, the philosophical instrument maker at Nürnberg, has discovered a law, the accuracy of which is confirmed by Ohm, for calculating from the weight of a horse-shoe magnet the load it will carry; or if the load be given, the weight of the magnet. This law he arrived at after performing a great number of experiments with horse-shoe magnets of all sizes, which had been magnetized to the point of saturation. (§ 452.)

Let $n$ be the ratio of the magnet's suspensive power to its weight, W its mass or weight, then

$$\text{I.)}\ a = n\sqrt[3]{W}$$

or $$\log. a = \log. n + \tfrac{1}{3} \log. W;$$

$a$ being a constant magnitude, which expresses the suspensive power of a magnet of some certain weight, which is assumed as the unit. M. Häcker selected 1 Bavarian loth $=\frac{1}{2}$ oz. English very nearly (the Bavarian lb. being $\frac{675}{567}$ths of the lb. avoirdupois, and the loth being the 32nd part of the lb.). From his experiments with a great number of horse-shoe magnets he found the mean value of log. $a = 1{\cdot}600$.

The above equation may be therefore converted thus: —

$$1{\cdot}600 = \log. n + \tfrac{1}{3} \log. W\ \tfrac{1}{2}\ \text{ounces};$$

Whence for the ratio of its suspensive power,

$$\log. n = 1{\cdot}600 - \tfrac{1}{3} \log. W$$

and for the weight,

$$\log. W = 3(1{\cdot}600 - \log. n).$$

Now let $z$ be the weight it will carry, then for $n$ in equation I.) substitute $\frac{z}{W}$, and we have

$$a = \frac{z}{\sqrt[3]{W^2}};$$

and, consequently, for its suspensive power,

$$z = a\sqrt[3]{W^2};$$

hence it is seen that the suspensive power $z$ increases as the square of the cube root of the mass: and the first equation shows that the ratio of the suspensive power $n$ is inversely as the cube root of the mass.

Let $w$ W express the weights, and $z$ Z the suspensive powers of two magnets, then they are to each other as

$$w^2 : W^2 = z^3 : Z^3,$$

or with equal values of $a$, the squares of the weights or masses of horse-shoe magnets are as the cubes of their suspensive forces.

To estimate exactly the intensity of magnetic forces, especially of small magnets (such as compass-needles), or to investigate the difference of such forces, we must have recourse to some other mode than that of finding the loads they would respectively carry. The most correct method is by means of Coulomb's Torsion Balance (§ 92.), or by experimenting on the oscillations made, as described in § 449.

The measurement of the magnetic intensity by the *vibrations a needle* performs depends on the law, that the force [illegible] of terrestrial mag- [illegible] which it performs the same [illegible] influence of the [illegible].

[illegible] discovered a law by [illegible] magnets the times [illegible] their magnetic inten- [illegible] and W their weights, is [illegible] then the following

$$[illegible] \frac{W}{L}$$

[illegible] M are indirectly, [illegible] as follows,

$$[illegible] \left(\frac{W}{L}\right)^2$$

[illegible] are proportional to the [illegible] their length into their

[illegible] oscillations. Coulomb [illegible] the attractive forces de- [illegible] distance. Thus, by this [illegible] needle, which under [illegible] performed 15 [illegible] oscillations in the [illegible] opposite pole of a magnet in [illegible] distance of 3 inches; [illegible] only 4 inches. In [illegible] and the attractive [illegible] 331 : 1456, or [illegible]

[illegible] (fig. 5. Vol. I. p. 35.), the theory [illegible] has already been explained in § 32.), be used as a magnetometer, to verify the preceding law, then for the bar substitute a magnetized needle, which is to come to a state of rest in the magnetic meridian, without the wire being thereby twisted. Now, bring this needle in the plane of its oscillations, turning it towards the similar pole of a magnet, and repulsion will, of course, ensue. We will suppose the angle of repulsion to be 24°, and if we give to it an opposite torsion of $3 \times 360 = 1080^\circ$, the deflection would be only 17°. But by the preceding experiments we already know that if the magnet of a torsion balance be turned 35°, it will be deflected about 1° from its polar position; if its deflexion be 24°, then the torsion it has suffered must be $24 \times 35 = 840^\circ$; if it be 17°, $17 \times 35 = 595$. Hence the deflecting power which causes an angle of repulsion of 24° is to that which causes an angle of repulsion of 17°, as $24 + 840 : 17 + 1080 + 595 = 864 : 1692$, or nearly as $1 : 2$, whilst the squares of the deflections will be as $24^2 : 17^2 = 576 : 289$, or nearly as $2 : 1$.

By means of this apparatus, the intensities of different magnets may be proved. For this purpose, deflect the needle of the torsion balance by the pole of the magnet under investigation, some certain distance from its normal position. By turning the wire in the opposite direction, the needle can be carried back to any angle of deflection whatever. With the pole of another magnet, or with some other part of the same magnet, proceed as before, taking care that the force shall act from the same point in each case, and that the needle is brought back to the same point. Then the intensities of the two magnetic forces are as the angles of torsion of the wire. For instance, if the needle must be turned back to 90°, in order that the magnet $m$ should deflect it 10°, and if it had to be turned 290° for another magnet M to deflect it as much, then the intensities of these two magnets would be as $90 + 10 = 100$ to $290 + 10 = 300$, or as $1 : 3$.

## § 457.

We have already (§ 438.) stated that magnetism may be induced in bodies susceptible of this influence, by merely bringing them within the atmosphere of either a natural or an artificial magnet: the part nearest to the magnet acquiring an opposite polarity to that of the pole, within whose magnetic circle it is placed.

This mode of exciting magnetism is far less effective than either contact or friction. It is more powerful in its influence on soft iron than on steel, for reasons already assigned (§ 452.); but in both, its effects are but temporary. — The experiments described in § 439. are a proof of this.

Terrestrial magnetism especially operates in this manner upon all bodies susceptible of this influence, as is seen in the magnetic properties acquired by bars of iron or steel placed in a vertical position, or better still, in the direction in which the directing force of the earth's magnetism acts. (§ 447.) Bodies so placed in the *northern hemisphere* have their upper extremities converted into south poles, and their lower ends into north poles. As far as polarity is concerned, these circumstances are reversed in the other hemisphere. — As a proof, see the experiment given in § 446.

## § 458.

Soft iron becomes magnetized by a variety of *mechanical operations*, which probably have the effect of disturbing the magnetic equilibrium of its constituent particles. Thus, an iron bar acquires magnetic properties by striking, filing, twisting, cooling rapidly, &c.; and it is a well known fact that iron and steel tools, such as gimlets, nail-passers, files, and the like, after having been some time in use, become so far magnetized as to take up iron-filings: an iron bar will be most quickly magnetized if subjected to such treatment while held in the position of the dipping-needle.

> *First Expt.* Hold an iron bar, about two feet long, in the position of the dipping-needle, and strike its upper end smartly with a hammer; its lower end will immediately become a tolerably powerful north pole, and the upper south pole. The magnetism thus imparted will be stil more powerful if the lower end of the bar be placed on mass of iron when struck.
>
> *Second Expt.* If a bar of iron be made red-hot, by which means its coercive power will be greatly lessened (§ 452.), and then plunged into a vessel of cold water (observing, at the same time, to hold it in the position of the dipping-needle), it will be found to be polarised, and to have acquired a considerable degree of magnetic force.

Upon these phenomena, it appears plain that these bodies are [illegible] rendered magnetic by induction from the earth, and [illegible] mechanical treatment to which they are subjected merely [illegible] them more readily to allow of the separation of the [illegible] forces.

## § 459.

[illegible] philosophers are of opinion that *magnetic virtue is* [illegible] *the sun's rays.* The results to which the [illegible] made for ascertaining this point have con- [illegible]. Small pieces of iron, or soft steel [illegible] had one end polished, and if this [illegible] to the action of the white light of [illegible] subjected to the violet rays of the [illegible] was produced still more speedily. In [illegible] permanent in its character, and

e illuminated end of the wire was a north pole. The mag-
tism thus induced is extremely feeble, and the experiment has
en successfully conducted only during the longest days of sum-
er, and under favourable circumstances as regarded the state of
e weather. These experiments have been repeated by other
ilosophers; but the results have been doubtful, and we are not
rranted in stating positively that the sun does possess any
agnetic influence.

Morichini, in 1812, was the first who announced that he had magnetized needles by exposing them for some time to the action of the violet rays of the solar spectrum, which he concentrated by means of a lens, and threw down on the needles. His colleague Barlocci believed that he accelerated the process and rendered the magnetism more intense, by moving the image of the violet rays from the middle of the needle towards the ends, which he placed north and south, moving it pretty much as we do a magnet when using it to impregnate a steel bar. Mrs. Somerville, in 1825, repeated Morichini's experiments with certain modifications; such as covering one half of the needle to be magnetized with paper, and exposing the naked half to the action of the violet rays. After some time she found the needle was rendered magnetic, and the end acted on by the light was a north pole. Professor Baumgartner, in 1826, found that needles from one-third to one-fourth of a line in thickness, if they were polished only at one end, and were either rough or stained with some dark colour in the other part, were rendered magnetic by exposure to the sun's rays, and that the polished end was invariably a north pole. Lastly, Zantedeschi, in 1829, verified the preceding experiments, and found that the needles must not be more than one-fourth of a line thick, and that they must not be too hard if the experiment is to be successful; and lastly, that the most favourable temperature for this purpose is from 77° to 91° Fahr.

Shortly after Morichini's announcement, Configliarchi called in question the accuracy of his statements; and Reiss and Moser are of opinion that the sun does not possess the magnetic properties some have been disposed to attribute to his rays, as in a set of experiments they performed at Berlin in 1829, they subjected the half of a number of needles two hundred times to a focus of violet light, and subsequently tested the duration of their oscillations without finding the least difference to have been caused which could lead them to believe they had been rendered magnetic.